FINAL REPORT

IMPACTS OF SUCTION DREDGE MINING ON ANADROMOUS FISH, INVERTEBRATES AND HABITAT IN CANYON CREEK, CALIFORNIA

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Thomas J. Hassler
William L. Somer
Gary R. Stern
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ABSTRACT

The popularity of the suction dredge for gold mining has greatly increased in recent years. The effect of dredge mining on anadromous fish and habitat is poorly understood and there is a need to assess its impacts. This study evaluated impacts of suction dredge mining on anadromous fish, invertebrates and habitat in Canyon Creek, Trinity River Basin California. Suction dredge mining in the lower 18 km of Canyon Creek is permitted from June 1 to September 15. Dredging is permitted until October 15 on tributary streams. The maximum permitted dredge intake hose size is 15.24 cm. Seventeen suction dredges operated yearly in Canyon Creek from 1980 through 1985. Dredging occurs in the wetted perimeter of the stream and a cone shaped hole is dredged. In 1984-1985, mean dredge hole depth was 1.3 meters, mean surface area disturbed by a dredge was 42 m^2 and total area disturbed was 1140 m^2. Canyon Creek has about 855 m^2 of suitable spawning gravel. About 6% of the area disturbed by dredging was visible the following year. Dredging activity did not appear to affect spawning site selection by chinook salmon and steelhead or the distribution of spring-run chinook salmon or summer-run steelhead holding in Canyon Creek. Salmon and steelhead were observed spawning in the vicinity of recent dredge activity, but fish did not spawn on dredge tailing piles. The effects on benthic invertebrate functional feeding groups were variable. Grazers and shredders were significantly more abundant above dredging and gatherers more abundant below. No significant impacts were noted for filterers. Some damage to the habitat occurred. Twelve percent of the dredgers channelized portions of the stream, 20% damaged some riparian habitat and 30% impacted a limited area of spawning gravel. The studies demonstrated that the impacts of suction dredge mining on fish and habitat were moderate at the current level of suction dredge activity. The impacts were seasonal and site specific. The current regulations controlling dredge aperature size and season appear adequate to protect habitat, but careful monitoring of mining activity is advised.

ACKNOWLEDGEMENTS

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INTRODUCTION

The use of the suction dredge in gold mining has increased in California in recent years as a result of high gold prices and the versatility of the portable suction dredge. The number of suction dredge permits issued annually by the California Department of Fish and Game (CFG) rose from 3,000 in 1975 to a high of 13,000 in 1980 and dropped to 7,300 in 1985. The effects of dredge mining on anadromous fish, benthic invertebrates, and habitat are poorly understood and there is a need to assess these impacts in order to make management decisions for riparian and aquatic habitats.

A number of studies have investigated the impacts of placer mining on aquatic life. Smith (1939) and Sumner and Smith (1940) found that salmonids avoided spawning in streams that were silted from placer mining in California. Casey (1959) observed the elimination of salmonids from a reach of stream degraded by a large dredge operation. Prokopovich and Nitzberg (1982) determined through petrographic analysis that much of the spawning gravels used by salmon in areas of the American River Basin were excaved by placer mining. LaPerriere (1984) observed a reduction in primary production from turbidities of 1665 nephelometric turbidity units (NTU) downstream of placer mines in Alaskan streams. In a related study, Reynolds (1984) found that Arctic grayling _Thymallus arcticus_ avoided streams with placer mining siltation.

The impacts of suction dredging on aquatic life and habitat depends on the size of the dredge and the extent of dredging. Campbell (1962) observed the effects of siltation on rainbow trout _Salmo gairdneri_ eyed eggs and fingerlings below a large gold dredge operation in the Powder River, Oregon. Eyed eggs maintained in hatching baskets had 100% mortality and fingerling 57% in the Powder River test area. Eyed eggs had 6% mortality and fingerling 9.5% in the Smith Creek control area. Griffith and Andrews (1981) measured mortality rates of eggs, sac fry, and fingerling trout after dredge entrainment. Uneyed cutthroat trout (_Salmo clarki_) eggs had 100% mortality and eyed eggs 35%. Rainbow trout sac fry had 83% mortality 20 days after entrainment. Lewis (1962) used a 12.7 cm aperature dredge in Clear Creek (Shasta County, California) to examine its effects on gravel and found that dredging could improve the intergravel environment for both fish eggs and benthos if the stream was uniformly mined. He also found dredge entrained benthos suffered a 7% mortality. Harvey et al. (1982) investigated the effects of suction dredge mining on fish, invertebrates and water quality in three Sierra streams. They observed significant localized alterations of the streambed and that the abundance of benthos and riffle sculpin Cottis gulosus was adversely affected.

Thomas (1985) used a 6.4 cm aperature dredge on a small Montana creek and studied the resulting physical and biological impacts. She found that suspended sediment returned to background levels within 11 m of suction dredge mining.

The effects of dredging on invertebrates is usually temporary and site specific. Lewis (1962) observed low invertebrate entrainment mortality and recolonization after 90 days. Griffith and Andrews (1981) observed that less than 1% of entrained invertebrates were injured or died within 24 hours and that stream areas were recolonized after 38 days. Harvey et al. (1982) found a significant localized alteration in benthic invertebrate communities due to dredging which was associated with changes in the degree of embeddedness of cobbles and boulders. Thomas (1985) found significant local alterations of benthic invertebrate abundance and recolonization within 30 days.

Dredgers cause damage to the habitat, especially when mining regulations are not followed. McCleneghan and Johnson (1983) surveyed 54 streams in California for suction dredge mining impacks and found that 88% of miners were operating within permit regulations. However, they observed the following instream dredge alterations: undercutting banks, channelizing stream, riparian damage, and bank sluicing.

The detrimental impacts of fine sediments on streams has been reviewed by several authors (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Fine sediment resulting from logging has been shown to impact fish habitat and trophic composition of benthic invertebrate communities (Tebo 1955; Burns 1972; Moring and Lantz 1975; Murphy and Hall 1981). High gradient stream systems are often less affected by logging sediments due to transport, but the sediment accumulates downstream (Newbold et al. 1980; Murphy et al. 1981). High silt loads observed in streams negatively impacted benthic invertebrates (Chutter 1968; Nuttall 1972). Artificial stream experiments have shown sedimentation impacts on benthic communities (Gammon 1970; Brusven and Prather 1971; Bjornn et al. 1974; Brusven and Prather 1974; Bjornn et al. 1977; McClelland and Brusven 1980). Sedimentation hampers upstream movements of benthic invertebrates (Luedtke and Brusven 1976), and increases downstream drift (Pearson and Franklin 1968).

Stream bottom composition determines the abundance and composition of benthic invertebrates (Erickson 1963; Cummins and Lauff 1969; Williams 1980). Substrate may determine benthic community structure through the extent of interstitial spaces (Minshall and Minshall 1977) and debris retention (Williams and Mundie 1978). Brusven and Rose (1981) demonstrated that sculpin predation on aquatic insects was significantly influenced by substrate composition. Conversely, stream gravel cleaning reduced benthic invertebrate populations in southeast Alaska streams (Meeham 1971). Benthos recolonization of a denuded stream is primarily through drift (Waters 1964).

Sediments have been found to have a negative impact on salmonids. Low hatching success has been reported for salmonids at high sediment concentrations (Shaw and Maga 1943; Cooper 1965; Shelton and Pollock 1966; Hausle and Coble 1976; Turnpenney and Williams 1980). Growth of salmon and trout was also low when sedimentation and turbidity were high (Cordone and Pennoyer 1960; Crouse et al. 1981; Sigler et al. 1984). Streambed alterations from sedimentation have resulted in reduced fish growth and standing crop (Rees 1959; Saunders and Smith 1965; Moyle 1976).

The objectives of this study were to assess the extent and impacts of suction dredge mining on juvenile and adult salmonids, benthic invertebrates, and habitat in Canyon Creek Trinity County California.

CANYON CREEK

Canyon Creek, a fourth order stream that drains 168 square km (Table 1), originates in glacial cirques and lakes of the Trinity Alps and flows south into the Trinity River at Junction City, California (Figure 1). During 1982-1985 summer flows in Canyon Creek range from 0.28 to 1.4 m^3/s and winter flows up to 42 m^3/s. Stream elevations along the 20.9 km access road range from 305 m at Junction City to 884 m at Globe Mill. Thompson Peak, 2744 m, is the highest point of the drainage. Forests of douglas fir (Pseudotsuga menziesii), incense cedar (Libocedrus decurrens), black oak (Quercus velutina), pacific madrone (Arbutus menziesii), and canyon live oak (Quercus chrysolepis), provide overhead stream cover along with species of alder (Alnus sp.), maple (Acer sp.), and willow (Salix sp.). The following fish species have been found in Canyon Creek: steelhead, chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), Klamath small scale sucker (Catostomus rimiculus), speckled dace (Rhinichthys osculus), pacific lamprey (Lampetra tridentata), and brown trout (S. trutta).

Table 1. Selected geomorphic variables for Canyon Creek drainage, Trinity County, California.[a]

Geomorphic variable	Canyon Creek
Drainage area (km^2)	167.8
Basin length (km)	29.8
Mainstem length (km)	32.3
Drainage density	1.16
Maximum basin relief (m)	2301.8
Basin relief ratio	0.077
Stream relief (m)	1266.7
Average stream gradient (%)	3.9
Channel length gutted by 1964 flood waters (km)	5.1
Average rainfall (cm)	139.4

[a]Mainstem Trinity River watershed erosion investigation. Dept. of Water Resources - Northern District. March. 1980.

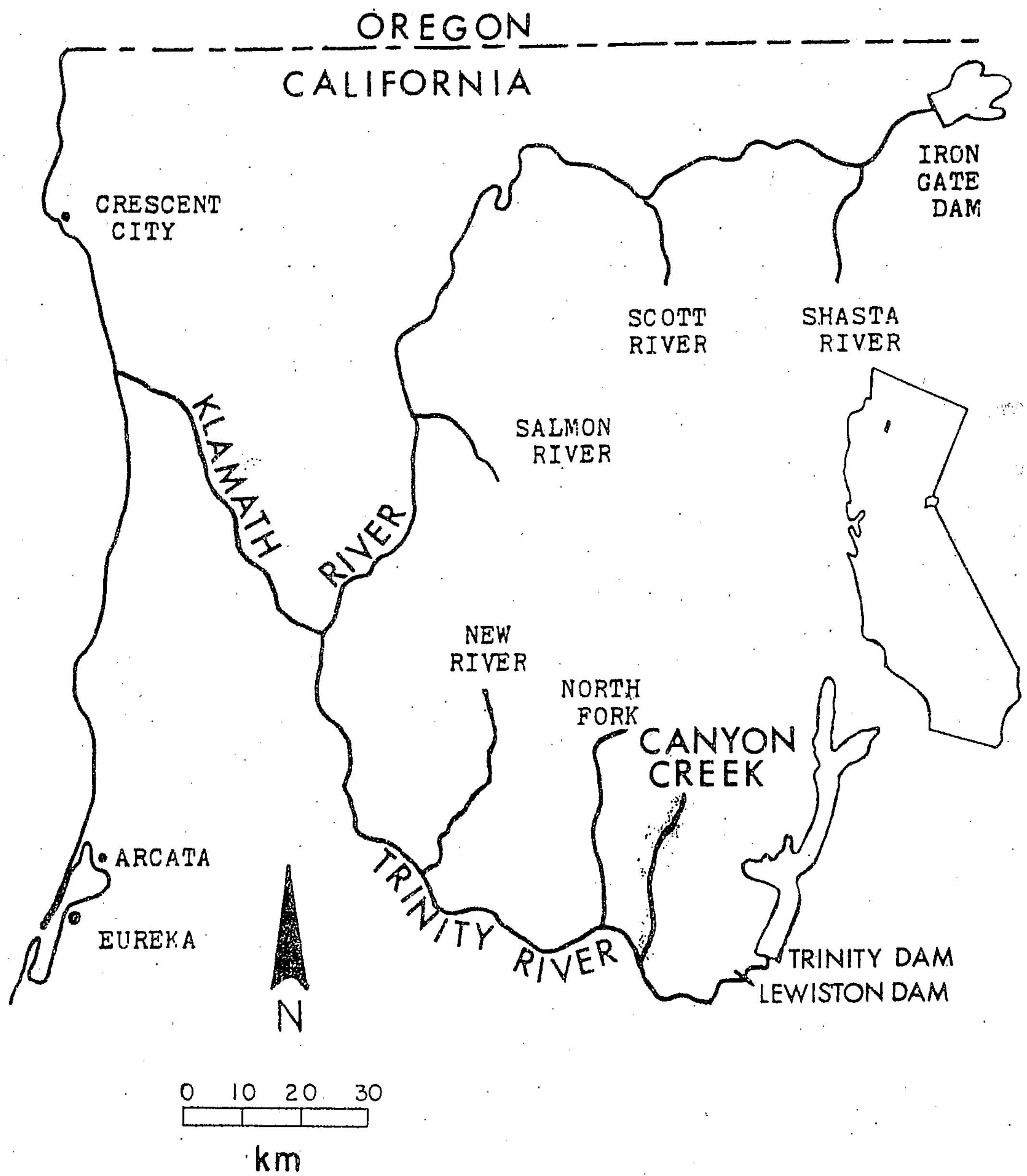

Figure 1. Klamath-Trinity River Basin California.

Stream gradient and instream and overhead cover are variable in Canyon Creek. The creek runs through an open canyon with large boulders and little overhead cover from above Globe Mill to 0.4 km above Ripstein. Boulder size decreases as the creek continues through Dedrick and Canyon City with varying amounts of overhead cover. Pools are numerous in low gradient areas of the stream, and some pools are deeper than 3 m. The lower 3 km of Canyon Creek opens into a wide gravel flood plain with no deep pools (Figure 2).

The Canyon Creek Basin is characterized by warm summers and mild winters, except in the upper drainage which experiences more severe winters. Most of the annual precipitation occurs from November through March (75 to 80%) with the balance evenly distributed over September, October, and April through June (Calif. Dept. Water Resources 1964). The average snow level is at an elevation of 1219 m.

Annual precipitation varies from 89 cm along the Trinity River to 203 cm in the Trinity Alps (Calif. Dept. Water Resources 1964). Average annual precipitation for the Canyon Creek area is 139 cm. Precipitation for 1983 water year (WY) (October 1982 - September 1983) was 187% of normal (mean based on a 45 year period from 1931 through 1975). Runoff into Trinity Reservoir at Lewiston, California in WY 1983 was 231% of average (Calif. Dept. Water Resources 1983). Rainfall in WYs 1983 - 1985 were 260 cm, 164 cm, and 113 cm, respectively.

Canyon Creek is within the Central Metamorphic Subprovice and two metamorphic rock units underlie the Creek - the Salmon Hornblende Schist, and the Abrams Mica Schist (Calif. Dept. Water Resources 1980). The Salmon Formation is thrust over the Abrams Formation (Irwin 1960). The two formations are considered the oldest of the Klamath Mountain region. The Abrams Formation, composed of metamorphosed sedimentary rock which includes the quartz-mica schists, interlayed marble, and quartzite or metachert (Irwin 1960). The mica schist was formed from clays and shaly sandstones. Slopes underlain by the schist are moderately stable, but solids are erodible (Calif. Dept. Water

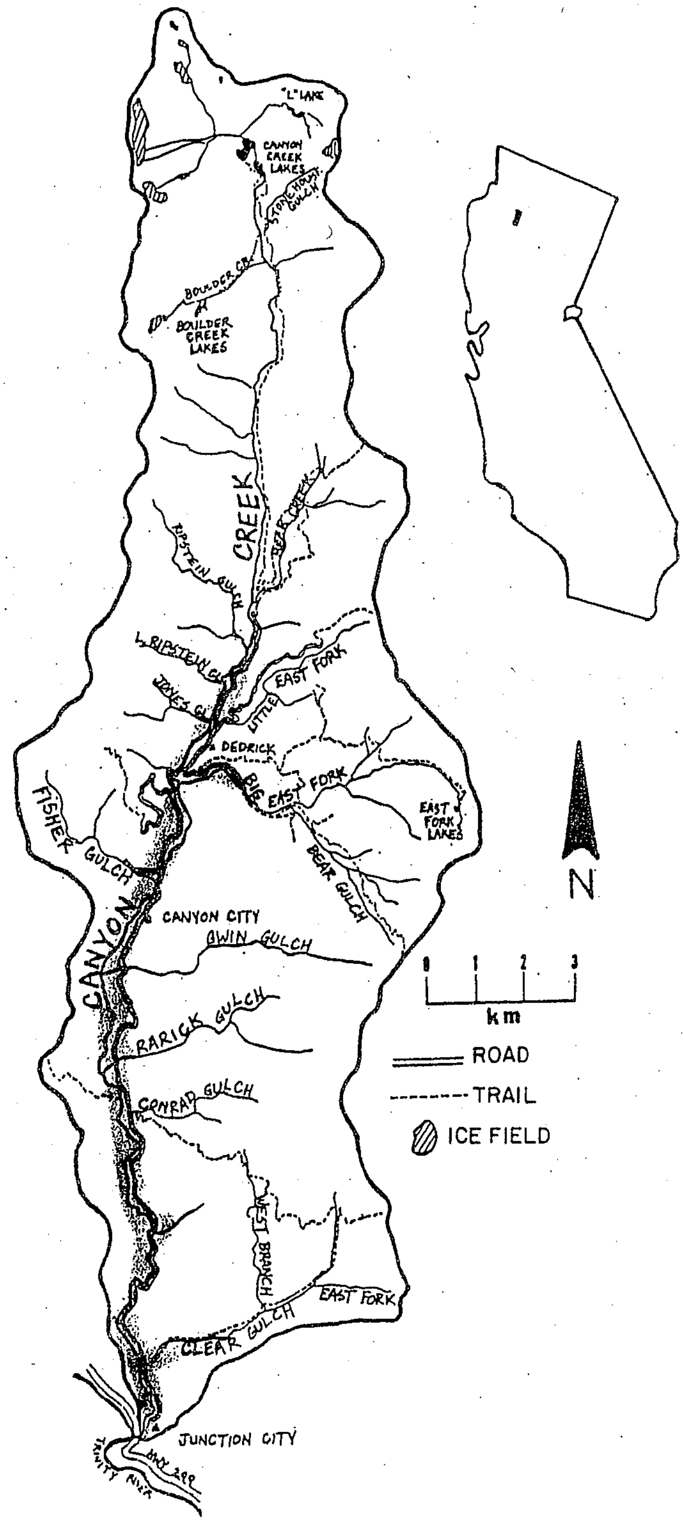

Figure 2. Canyon Creek Basin with study area outlined.

Resources 1980). The quartzite deposits were formed from quartz sandstones. The Salmon Formation is composed of hornblende schists (Irwin 1960) which are thought to have been formed from volcanic rocks, predominatly mafic flows and pyroclastic rocks. The Salmon hornblende schist is erodible, and releases large amounts of clay-sized amphibole crystals into the Trinity River (Calif. Dept. Water Resources 1980).

Placer deposits of gold are the products of erosion, transportation, and gravitational concentration of lode gold. Along Canyon Creek, gold-bearing gravel deposits are 50 to 75 feet thick (Cox 1967). Lode and placer mining began in the Canyon Creek area as early as 1850 (Gudde 1975). Canyon City, founded in 1851 (Jones 1981) and Dedrick in 1890 (Dunn 1893) were early gold mining communities. Drift mining was extensive from 1851 through 1857 in Canyon City area (Dunn 1893). Several lode mines operated in the Dedrick area from the 1890's through the 1930's (Clark 1970). Terrace gravels in the Canyon Creek Basin were excavated extensively by hydraulic mining during the late 1800's, and again during the 1930's (Averill 1941). Placer deposits in Canyon Creek, as in most of California's mining country, have been more productive for gold than other forms of mining (Irwin 1960).

The dredge mining season in Canyon Creek extends from June 1 to September 15. Dredging is permitted until October 15 on tributary creeks. The maximum suction dredge intake hose size is 15.2 cm, although one 20.3 cm dredge has been operated by special permit. Some resident miners reported dredge mining for as long as ten years.

The lower 18 km of Canyon Creek were surveyed for dredge activity, fish distribution and spawning and as fish habitat (Figure 2). The impacts of suction dredge mining on benthic invertebrates were investigated at Canyon Creek and Big East Fork of Canyon Creek. Big East Fork Creek (BEF) is a high gradient (10 to 15%) third order stream that enters Canyon Creek 17 river km upstream from Canyon Creek's confluence with the Trinity River.

MATERIALS AND METHODS

Suction Dredge Mining

The lower 18 km of Canyon Creek were surveyed for dredge mining throughout the 1982-1985 dredging seasons, June 1 to September 15 (Figure 2). At each suction dredge operation in 1984 and 1985 the size of dredge intake hose, number of persons working the operation, and dates of dredge operation were obtained. Dredgers were classed as professional or recreational. After the 1984 and 1985 dredge seasons, all dredge-created holes in the streambed were identified and the length, width and depth of each dredge hole was measured. The surface area of dredge tailings were divided into 5 size classes, boulder (greater than 250 mm), cobble (250-128 mm), large gravel (128-32 mm), small gravel (32-4 mm) and fines (less than 4 mm) and measured. Determination of operational impacts at each dredge site were assessed as in McCleneghan and Johnson (1983). Impacts included stream channelization, bank undercutting, riparian damage, sluicing of the bank and impact upon suitable spawning gravels. In the summers of 1985 and 1986, each dredge hole from the 1984 and 1985 mining season was remeasured to determine the amount of hole and tailings remaining. A longitudinal profile of a large dredge hole was constructed from cross section measurements taken in October 1984 and July 1985.

Channel Morphology

Stream gaging stations and channel cross sections were established (1984-1985) along the lower 16 km of Canyon Creek (Figure 3). Gage 1 was operated from January 1984 to September 1985, gage 2 from July-October 1984 and gage 3 from October 1984 to September 1985. At each gaging station a staff gage was installed and periodic discharge measurements were taken with a pygmy or Price AA current meter. A gage stage-stream discharge relationship was established by regression analysis; wetted perimeter, depth and

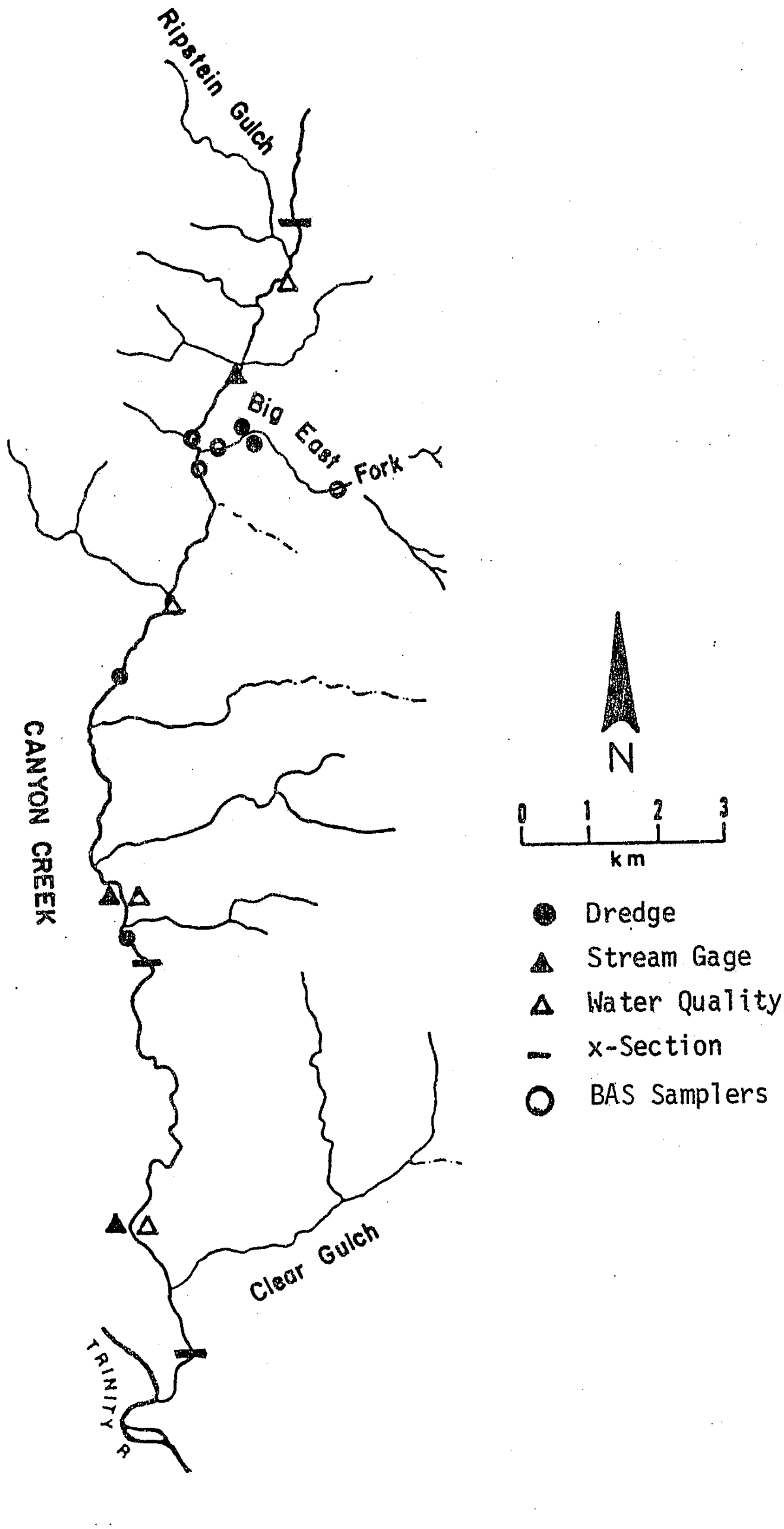

Figure 3. Sampling stations at Canyon Creek, Trinity County, California.

velocity also were measured. Canyon Creek was divided into 3 sections based on stream substrate, gradient and channel configuration and a cross section was established in each section. At each cross section the following channel parameters were measured: geometric mean particle diameter and Manning's n determined by pebble count (Dunne and Leopold 1978); embeddedness by an ocular rating of substrate characteristics (Platts et al. 1983); bankfull channel dimension and discharge estimated by cross-sectional channel survey with level and stadia rod, and examination of channel bankfull indicators (Dunne and Leopold 1978). Channel stability was estimated between July 1984 and July 1985. Streambed aggredation/degradation rates were calculated and the net change of cross-sectional area determined.

Water Quality

Water quality parameters were measured at 4 stations along the lower 16 km of Canyon Creek during 1982-1985 (Figure 3). Stream temperatures were measured with a pocket thermometer, maximum and minimum thermometer and a recording thermograph. Water samples were collected with a DH-48 depth-intergrating sampler (Guy 1970). All water samples were analyzed for turbidity by a Hach Turbidimeter Model 2100A and conductivity by a Beckman Solubridge Type R.B.-5. Some samples were analyzed for suspended sediment and total dissolved solids. Suspended sediment was determined by filtration of 100 ml of sampled water through Whatman GF/C filter paper. Residue was dried at $100^{o}C$ for one hour and weighed. Total dissolved solids were measured by evaporation of the filtrate for 24 hours at $100^{o}C$ and then weighing the residue.

Dredge Impacts

During the 1985 mining season, two suction dredge operations on Canyon Creek were monitored to assess dredge impacts on channel morphology, water quality, fish habitat and number of steelhead young-of-year (Figure 3). At both dredge sites transects were established at 4, 9, 16, 25, 36 and 49 m below the dredge and one site upstream of dredge with channel characteristics similar to below dredge zone. Along each transect the following (pre- and post-mining) streambed parameters were measured: Channel cross-section, surved with level and stadia rod; substrate particle diameter from pebble counts (Dunne and Leopold 1978); one hundred pebbles were examined and divided into 13 size classes (modified Wentworth scale) for calculation of geometric mean particle size (dg) and a sorting coefficient (So) (Platts et al. 1983); embeddedness determined by an ocular rating of substrate characteristics (Platts et al. 1983). During dredging, water samples were collected with a DH-48 sampler along each transect. Turbidity and suspended sediments were measured as previously described.

Sediment deposition was measured during dredging at upper dredge (site 1) 4, 9 and 16 m below dredge and above dredge and at lower dredge (site 2) 4, 9, 16 and 25 m below dredge and above dredge. Deposited sediment (less than 2 mm) was sampled by burying 3 cans (15.24 cm diameter) filled with washed, rounded gravels (2.5 to 10.2 cm diameter) flush with the substrate surface along each transect (Meeham and Swanson 1977). Cans were removed after 24 hours (2.5 hours of dredge mining). The gravel was removed from each can and sediment dried at 100^{o}C for 3 hours. Dry sediment was sieved on a shaker for 10 minutes into 7 size classes (greater than 2 mm, 2-1 mm, 1-0.5 mm, 0.5-0.25 mm, 0.25-0.125 mm, 0.125-0.063 mm and less than 0.063 mm) and each size weighed.

To assess the influence of dredging activity on salmonid juveniles, a 30 m length of stream (20-50 m) below dredge and a 30 m length of stream above dredge were dove for direct observation of fish before and after dredging.

Juvenile Fish

Nine juvenile fish sampling stations were established in the lower 18 km of Canyon Creek (Figure 4). At each station 100 feet of stream were blocked with nets and sampled

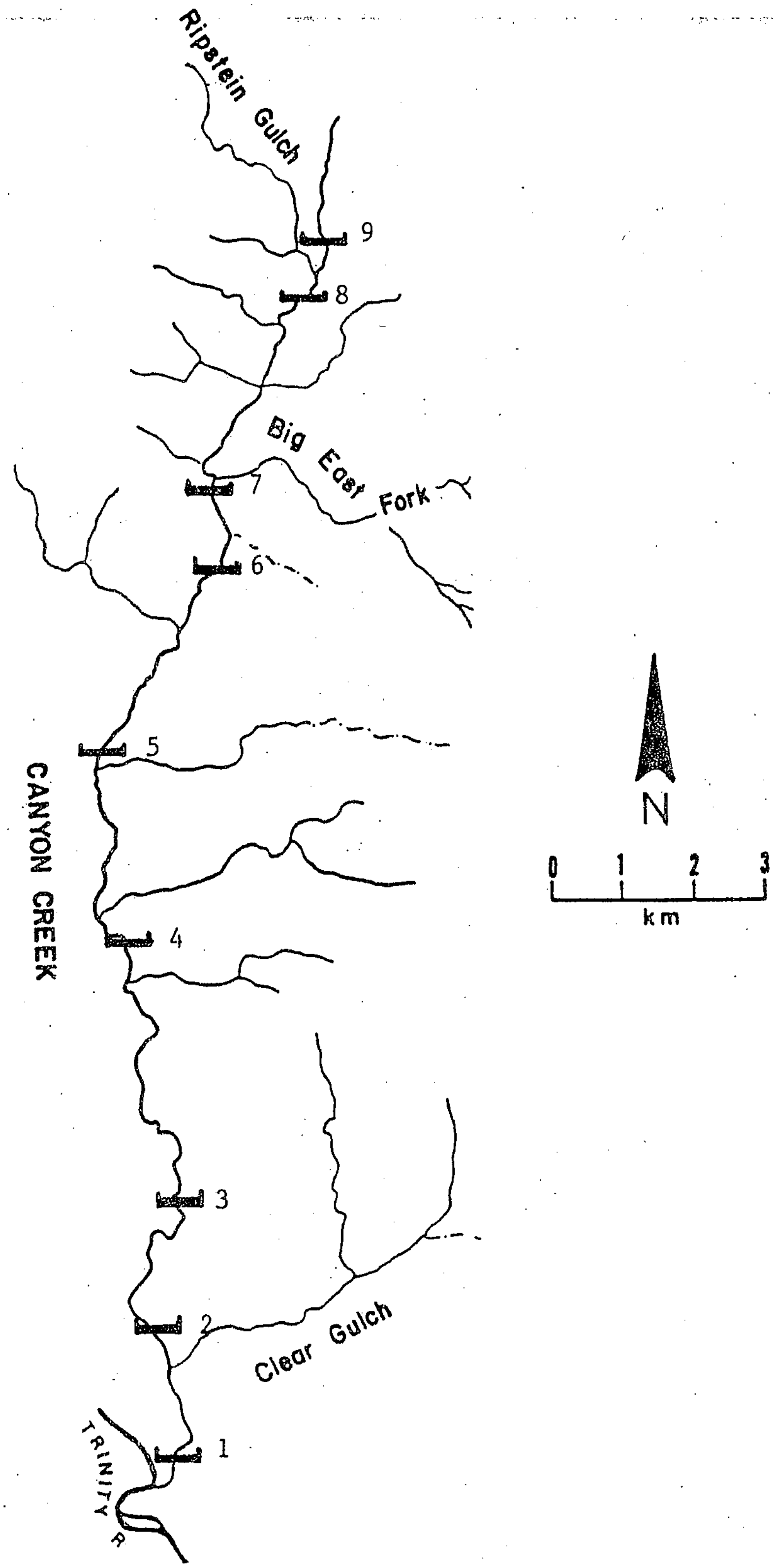

Figure 4. Juvenile fish sampling stations at Canyon Creek, Trinity County, California.

with a backpack electroshocker in September. In 1982, all stations were electrofished, in 1983, stations 1, 5 and 8 and in 1984 stations 1, 4, 5 and 8. Fish were counted, measured fork length (FL) weighed (g) and a subsample preserved in 7% formalin and transferred to 70% ethanol. In 1984, fish were measured and weighed in the field and a sample preserved. Only 17 juvenile coho salmon were captured and they were not included in population analysis. The number of juvenile steelhead per station was estimated each September with the multiple pass Moran and Zippen method (Everhart et al. 1975). The program Growth (Collins 1977) was used to compute the following: length-weight relationship, condition factor and body length-scale length relationship. The relation between the length and weight of living and preserved fish was determined by regression analysis. Steelhead biomass in the fall of each year was calculated from corrected preserved weights and population estimates of young of year and juvenile steelhead.

Stomach contents of 70 steelhead sampled in September 1982 were analyzed. Organisms were keyed to the lowest taxa, counted and volume measured. Taxa volume per stomach was determined by water displacement in a pipet to 0.001 ml. Fish collected at the stations were combined by stream area for stomach analysis as follows: Stations 1 and 2 (lower stream), stations 4, 5 and 6 (mid stream) and stations 8 and 9 (up stream).

Adult Fish

The lower 18 km of Canyon Creek were surveyed for adult salmonids holding and spawning in the creek. Pools and runs deeper than 0.6 m were examined for spring chinook salmon and summer steelhead in August (1982, 1983, 1985). Divers identified species, estimated total length and noted tags and fin clips for each fish longer than about 40 cm. High stream flows in 1983 precluded an accurate survey. A biweekly survey during the spawning season (October-May) in 1983-1985 and fall of 1985 was conducted to locate salmonid redds. Redd length was measured from the upstream edge of the excavated pit to the downstream edge of the tailspin. Width was measured across the mid-portion of the redd in the vicinity of the mound. Redd area was determined by multiplying length by width. Water velocity, taken at 0.12 m depth with a pygmy current meter, and water depth were measured at the upstream edge of each redd or approximately 0.5 m laterally from the redd. Substrate composition at the spawning areas was determined as described by McNeil and Ahnell (1964). Al substrate was sieved dry on a shaker for 10 minutes. The twelve sieves ranged from 0.063 mm to 76.1 mm . Geometric mean particle diameter and the fredle index were calculated for each substrate sample (Lotspeich and Everest 1981). Total suitable spawning gravel area in Canyon Creek was estimated by measuring all areas that contained at least 3.5 m^2 of spawning gravel (at a discharge of about 4 m^3/s) during January-March 1985. Stream edges and side channels were scanned visually for fry during the biweekly spawning surveys. Limited electroshocking of side channels was conducted during spring 1984 and 1985. High water flows limited observations.

Invertebrates

A basket type artificial substrate (BAS) was used to sample aquatic invertebrates. The sampler was 25.4 cm long, 10.2 cm wide and 6.4 cm high with a volume of 1658 cm^3 and constructed of 1.3 cm mesh hardware cloth (Figure 5). The sampler was filled with rounded, washed graded cobble 1.9 cm to 3.8 cm diameter. The BAS samplers were placed as follows: Site 1, BEF above dredge; Site 2, BEF (40-113 m) below dredge; Site 3, Canyon Creek above BEF; and Site 4, Canyon Creek below BEF (Figure 3). Sites on both creeks had similar substrate, tree cover and slope. Two 4 inch suction dredges operated from August 3, 1983 to October 4, 1983. A study was conducted at Site 3 in April 1983 to determine sample sized as described by Platts et al. (1983). At each site a grid was mapped and BAS samplers were placed at similar depth, velocity and substrate. The samplers were set flush with stream substrate. At Site 1 and 2, 28 BAS samplers

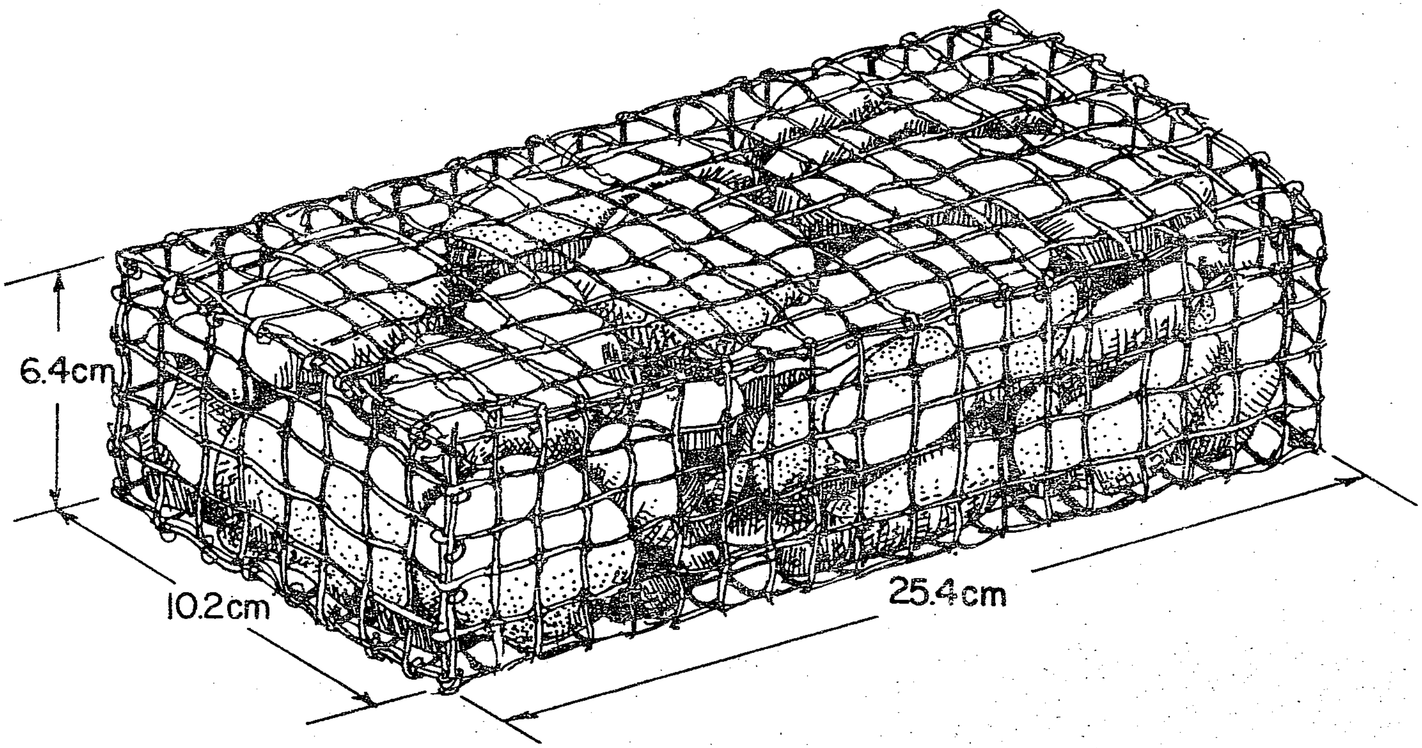

Figure 5. Artificial substrate sampler.

were set at each site and at Site 3 and 4, 14 at each site. Sampler placement began August 31 and was completed September 2, 1983. Seven samplers were removed after 2, 4 and 6 week colonization intervals at Site 1 and 2 and 7 samplers at Site 3 and 4 after 4 weeks. High stream flows prevented sampler removal one month after dredging stopped. Samplers were removed at random from a site and approached from downstream. Upon removal, the sampler was quickly placed in a 10 mesh/cm net. Water depth and velocity were measured at each sampler with a pygmy current meter. Samplers were dismantled in a bucket and invertebrates, organic matter and sediment were separated from the rocks by rinsing through a 1.27 cm mesh Tyler sieve. Sampler rocks and organic matter were placed in an irritant solution (Britt 1955) to dislodge clinging organisms. Sampler rocks were also cleaned gently with a soft brush. Samples were poured through a No. 70 Tyler sieve. Invertebrates were hand sorted from samples; organic matter and sediment was separated by density flotation (Slack et al. 1973). Organic matter and sediment were dried in an oven at 100^{o}C for 12 hours and weighed. Invertebrates were keyed under a dissecting scope to the lowest identifiable taxa with Usinger (1956), Allen and Edmunds (1961), Allen and Edmunds (1962), Allen and Edmunds (1963), Allen and Edmunds (1965), Allen (1968), Brown (1972), Wiggins (1977), Kaston (1978), Edmunds et al. (1979) and Merritt and Cummins (1984). Chironomid larvae were cleaned and mounted (Bryce and Hobart 1972; Weber 1973) and keyed under a compound scope using Merritt and Cummins (1984).

The Shannon-Weaver diversity index (Wilhm and Dorris 1968) was used to determine diversity per sampler. Diversity (H') was calculated as:

$$H' = - \sum_{i=i}^{s} \left(\frac{Ni}{N}\right) \log_e \left(\frac{Ni}{N}\right)$$

where: Ni = number of organisms of taxa "i" in sample; N = total number of organisms in sample; and s = number of taxa in sample. The equitability index (Platts et al. 1983) was employed to examine the evenness of allotment of individuals among taxa. Equitability (e) was calculated as:

$$e' = \frac{S^*}{S}$$

where: S = number of taxa in sample and S* = hypothetical number of taxa based on the diversity index (H') for a sample.

Invertebrate taxa were classified to a specific ecological functional group based on the trophic feeding strategy that particular organisms assume in a community. Functional groups were classified from Merritt and Cummins (1984) as follows: Predators - carnivores which attack prey and ingest whole animals or parts; shredders - detritivores which consume decomposing vascular plant tissue; scrapers - herbivores that graze on algae and periphyton; filterers - herbivore-detritivores which filter or suspension feed on algal cells, or decomposing organic matter; gatherers - detritivores that are sediment or deposit feeders on decomposing organic matter.

The invertebrate data was transformed by log (x+1). Homogeneity of transformed data was tested with the Hartley F-Max test (Sokal and Rohlf 1981) and normality using the G-test (Sokal and Rohlf 1981), and frequency histograms. A two-way analysis of variance (ANOVA) was performed on all colonization periods at BEF (site x time). Interaction effects (site x time) were investigated with ANOVA, and Tukey and Scheffe multiple range tests (Sokal and Rohlf 1981). A separate two-way ANOVA was performed on week four samples from BEF and Canyon Creek (site x creek). Sediment and organic matter collected in BAS samplers was analyzed after log(x+1) transformation with two-way ANOVA tests with taxonomic groups. Descriptive statistics and ANOVA were computed on SPSS programs Condescriptive and ANOVA (Nie et al. 1975); and BMDP program 5D (Dixon 1981).

Abundance of common taxa in artificial substrate samplers was investigated in terms of physical habitat variables (depth, velocity, organic matter, and sediment). All variables were subjected to the following transformations: 1/sq rt(y+1), sq rt(y+1), ln(y+1), 1/(y+1), and log(y+1) (Sokal and Rohlf 1981). These nominal distributions were examined for normality with the programs: SPSS Condescriptive (Nie et al. 1975), and BMDP program 5d (Dixon 1981). Independent habitat variables were investigated with principal component analysis. Common taxa were used as a dependent variable in a regression on the independent principal components. Principal components analysis and regression on principal components was performed with BMDP programs 4m and 4r (Dixon 1981). Examination of the factor structure matrix and the correlation matrix of dependent variables revealed no clear advantage of principal components analysis over multiple regression. Therefore, physical habitat variables were entered into a multiple regression with taxa. Multiple regression was performed with BMDP program 1r (Dixon 1981).

Kick samples were taken downstream of a BAS site during each sampler removal period in similar stream habitat. Invertebrates and detritus were preserved in 70% ethanol for laboratory sorting and keying. Invertebrates were sorted from detritus and keyed to lowest taxa as described previously. Percentage composition of functional groups and diversity indices were compared with artificial substrate samples.

A twenty four hour drift study was conducted on October 8, 1983 at 1000, 1400, and 2200 hours. One drift net was secured in the water column, for 30 minutes each sampling period, downstream of BAS samplers with the top of the drift net submerged to avoid excess leaf clutter. The drift net had a 930 cm^2 area with 1.14 mesh/mm. Samples were concentrated on a No. 70 Tyler sieve and preserved in 70% ethanol. Invertebrates were sorted from detritus and keyed to lowest taxa as described previously.

Water samples were collected weekly at 30.5 cm intervals with a DH-48 depth integrating sediment sampler at transects 2 m below BAS samples. Discharge was measured at a transect with a Pygmy current meter. Temperature was monitored at all BAS sites with Ryan thermographs. Conductivity, settleable solids and turbidity were measured in the laboratory as previously described within 24 hours. Water samples were filtered through a No. 40 Whatman filter and the residue was dried at 100°C for one hour, and weighed. Sample volume was recorded to calculate mg settleable solids/1. Regression analysis were used to describe the relation between settleable solids and turbidity, and flow; and turbidity and flow.

Cans (15.24 cm diameter) filled with washed stream cobble (1.9 cm to 3.8 cm) were placed flush with stream bottom to measure sedimentation rate. Sixteen cans (sediment traps) were placed in transects at BAS sampler sites. Two cans were removed at Sites 1 and 4 after the 4-week BAS sampling interval. Four cans were removed at Site 1 and 2 after the 6-week BAS sampling period. Additional cans were placed after the 6-week period to measure siltation levels after dredging ceased; however, high water prevented their removal. Upon removal, samples were sieved with a 6.35 mm Tyler screen to separate cobble from trapped sediments. Sediment samples were sieved to 0.208 mm, 0.104 mm, 0.063 mm, and fines, dried at 100°C for 12 hours and the fractions weighed.

RESULTS

Suction Dredge Mining

Suction dredges operated in the lower 18 km of Canyon Creek. Data on dredge mining were compiled from interviews, dredge site inspections, and transect measurements before and after dredging in 1982-1985 (Table 2). Dredging occurred in the wetted perimeter of the stream and a cone shaped hole was dredged. Ten percent of the dredgers channelized portions of the stream, 15% caused riparian damage, 4% damaged bank and 36% impacted suitable spawning gravels. In 1984, 24 suction dredges operated in Canyon Creek and excavated 30 holes in the streambed, mean depth 1.21 m SD 0.46 (Table 3). The mean surface area disturbed by a dredge hole and tailing piles was 38.80 m^2 SD 60.08. In 1984, dredge mining activities disturbed 1164 m^2 of streambed. One year later only 102 m^2 (9%) of the disturbed streambed were visible. The bottom contour of dredge hole 15, a large hole which did not completely fill-in one year later in 1985 is presented in Figure 6. In 1985, 18 suction dredges operated in Canyon Creek and excavated 22 holes in the streambed, mean depth 1.49 m SD 0.31 (Table 4). The mean surface area disturbed by a hole and tailings was 48.88 m^2 SD 46.63. A total of 1075 m^2 was disturbed by dredge mining activities in 1985. One year later only 43 m^2 (4%) of the disturbed streambed were visible.

Channel Morphology and Water Quality

In Water Year 1985 (WY 1985), streamflow in Canyon Creek varied from a mean winter (December 22 to March 21) discharge of 3.28 m^3/s to a mean summer (June 22 to September 23) discharge of 0.92 m^3/s. A hydrograph and flow duration curve during WY 1985 for Canyon Creek are presented in Figures 7 and 8. Instantaneous peak discharges of 23.7, 11.2, 14.7 and 14.3 m^3/s were recorded from November 1984 to April 1985. Gage

Table 2. Suction dredge mining activities in Canyon Creek, Trinity County, California.

Mining activities	Year				
	1980	1982	1983	1984	1985
No. dredges	19	19	7	24	18
Dredge diameter (cm):					
6.35				4	
7.6	3	1		3	1
10.2	1	8	5	7	8
12.7	2	1		3	8
15.2	3	6		5	
20.3		1			
?	10	2	2	2	1
No. dredge operations	10	10	5	20	14
No. operating plans filed with USFS[a]	9	9	11	5	8
Mean dredge hole depth (m) (± SD)				1.21 (0.46)	1.49 (0.31)
Mean surface area disturbed (m^2) (± SD)				38.80 (60.08)	48.88 (46.63)
Total surface area disturbed (m^2)				1164.0	1075.3
Disturbed area visible following year (m^2)				101.6 (8.7%)	43 (4%)
Professional dredgers				13	7
Dredgers that					
Channelized		3	1	3	2
Damaged riparian		4	2	5	2
Sluiced bank		0	1	0	1
Undercut bank		3	3	5	5
Impacted suitable spawning gravels		-	-	8	7

[a]Plan of operations filed with U.S. Forest Service - Big Bar Ranger District, Trinity National Forest, California.

Table 3. Suction dredge hole parameters in 1984, Canyon Creek, Trinity County, California.

Dredge hole	Dredge diameter (cm) 6.35	7.6	10.2	12.7	15.2	?	Dredge hole: Depth (m)	Length (m)	Width (m)	Surface area (m²)	Tailings surface area (m²)	Total surface area disturbed (m²)	Total surface area disturbed visible following year (m²)	Bank undercut (m²)	Profes-sional dredger	Operation impacts: Channeli-zation	Riparian damage	Impacted suitable spawning gravels
1					x		0.9	3.7	2.7	10.0	4.8	14.8	0.6	0.5				
2		x					0.5	4.6	2.1	9.8	25.7	35.5					x	
3						x	0.5	2.4	2.1	5.2	9.9	15.1						x
4					x		1.5	5.5	4.6	25.1	19.6	44.7						
5					x		1.2	3.0	2.1	6.5	7.4	13.9			x			x
6					x		1.2	2.7	3.4	9.2	12.3	21.5			x			
7			x				1.1	4.6	4.0	18.1	12.1	31.2			x			
8			x				1.5	5.5	4.6	25.1	23.8	48.9			x			
9			x				1.2	4.9	3.7	17.8	12.1	29.9			x			x
10			x				1.2	4.0	1.5	6.0	4.8	10.8			x			
11	x						0.6	4.0	2.9	11.5	11.5	23.0			x			
12					x		2.4	7.6	6.1	46.5	15.3	61.8						
13				x			1.5	6.4	2.4	15.6	18.7	34.3	1.5	1.8	x		x	x
14			x				1.4	4.6	3.0	13.9	21.6	35.5	0.1					
15					x		2.4	13.1	5.5	71.9	91.5	163.4	1.5		x	x		
16	x						0.9	2.1	1.8	3.9	9.5	13.4	11.1		x		x	x
17			x				0.9	1.8	3.0	5.6	13.4	19.0	2.3					
18	x				x		2.1	12.8	6.6	83.9	237.9	321.8		1.8	x	x		
19		x					0.9	1.8	1.8	3.3	0.1	3.4	78.7			x		x
20		x					0.9	2.4	1.5	3.7	2.2	5.9		0.4	x		x	
21						x	1.2	3.0	2.4	7.4	14.9	22.3						
22						x	1.2	1.5	2.4	3.7	5.6	9.3						
23						x	1.2	2.7	2.1	5.9	6.7	12.6						
24			x				0.9	3.2	3.4	27.6	11.9	39.5	5.8	2.0			x	
25	x						0.9	6.1	3.7	22.3	1.9	24.2						
26						x	1.6	1.8	4.6	8.4	9.8	18.2						
27			x				0.9	2.7	1.4	3.8	1.4	5.2						
28			x				1.2	2.1	1.2	2.6	0	2.6						
29					x		1.5	4.9	3.0	14.9	41.0	55.9						
30						x	0.9	4.9	3.7	17.8	8.9	26.7			x			x x

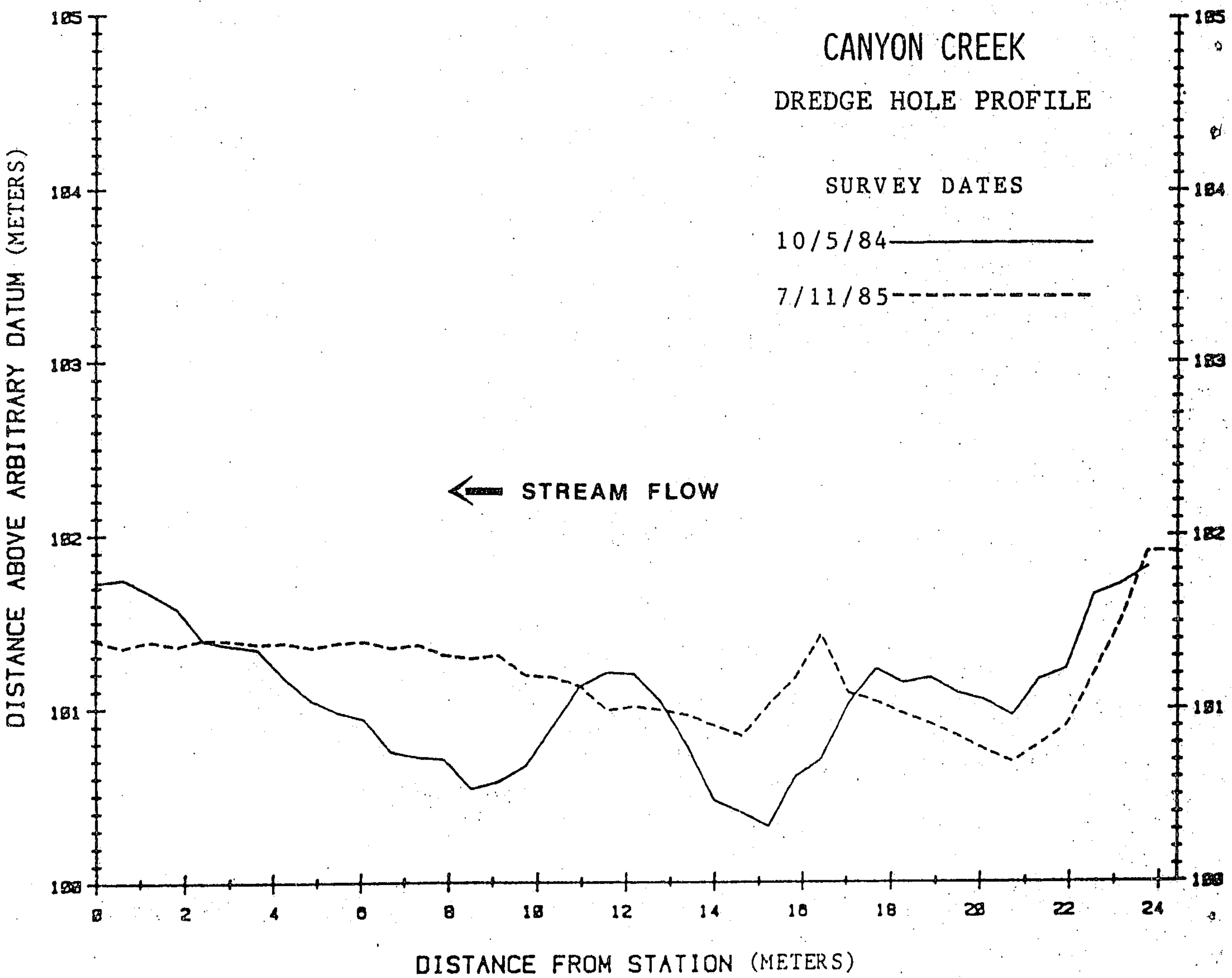

Figure 6. Bottom contour of suction dredge hole in Canyon Creek, Trinity County, California.

Table 4. Suction dredge hole parameters in 1985, Canyon Creek, Trinity County, California.

Dredge hole	Dredge diameter (cm)						Dredge hole								Operation impacts		
	6.35	7.6	10.2	12.7	15.2	?	Depth (m)	Length (m)	Width (m)	Surface area (m^2)	Tailings surface area (m^2)	Total surface area disturbed (m^2)	Bank undercut (m^2)	Professional dredger	Channelization	Riparian damage	Impacted suitable spawning gravels
1			x				1.2	4.3	2.4	10.4	21.5	31.9					
2			x				1.5	2.4	2.1	5.2	11.7	16.9					x
3			x				1.7	4.0	3.2	12.7	20.7	33.4	1.1			x	
4				x			1.4	3.7	2.1	7.8	7.2	15.0		x			
5			x				1.1	2.1	2.7	5.9	11.1	17.0		x			x
6				x			1.1	2.7	3.0	8.4	0	8.4					
7				x			1.5	10.7	4.3	45.5	55.5	101.0	4.9				x
8						x	1.8	6.1	7.6	46.5	26.0	72.5		x			
9			x				1.1	1.8	5.5	10.0	49.4	59.4	1.3				x
10			x				1.4	6.1	2.7	16.7	21.4	38.1	1.4	x			
11				x			2.0	6.1	5.2	31.6	66.5	98.1	2.2		x		x
12			x				1.5	3.0	4.3	13.0	41.3	54.3		x	x		
13			x				1.1	2.7	2.4	6.7	24.5	31.2		x			
14				x			1.5	3.7	2.7	10.0	14.1	24.1					
15			x				1.5	2.4	6.1	14.9	30.7	45.6					
16			x				1.8	3.7	7.3	26.8	24.2	51.0					x
17				x			0.8	3.0	1.8	5.6	3.3	8.9					x
18			x				1.8	6.1	5.5	33.4	21.7	55.1				x	
19				x			1.8	3.7	6.1	22.3	35.7	58.0	0.4				
20		x		x			1.8	15.2	7.6	116.1	110.2	226.3	0.9	x			
21				x			1.5	1.8	2.4	4.5	6.1	10.6					
22				x			1.8	2.7	3.0	8.4	10.0	18.4					

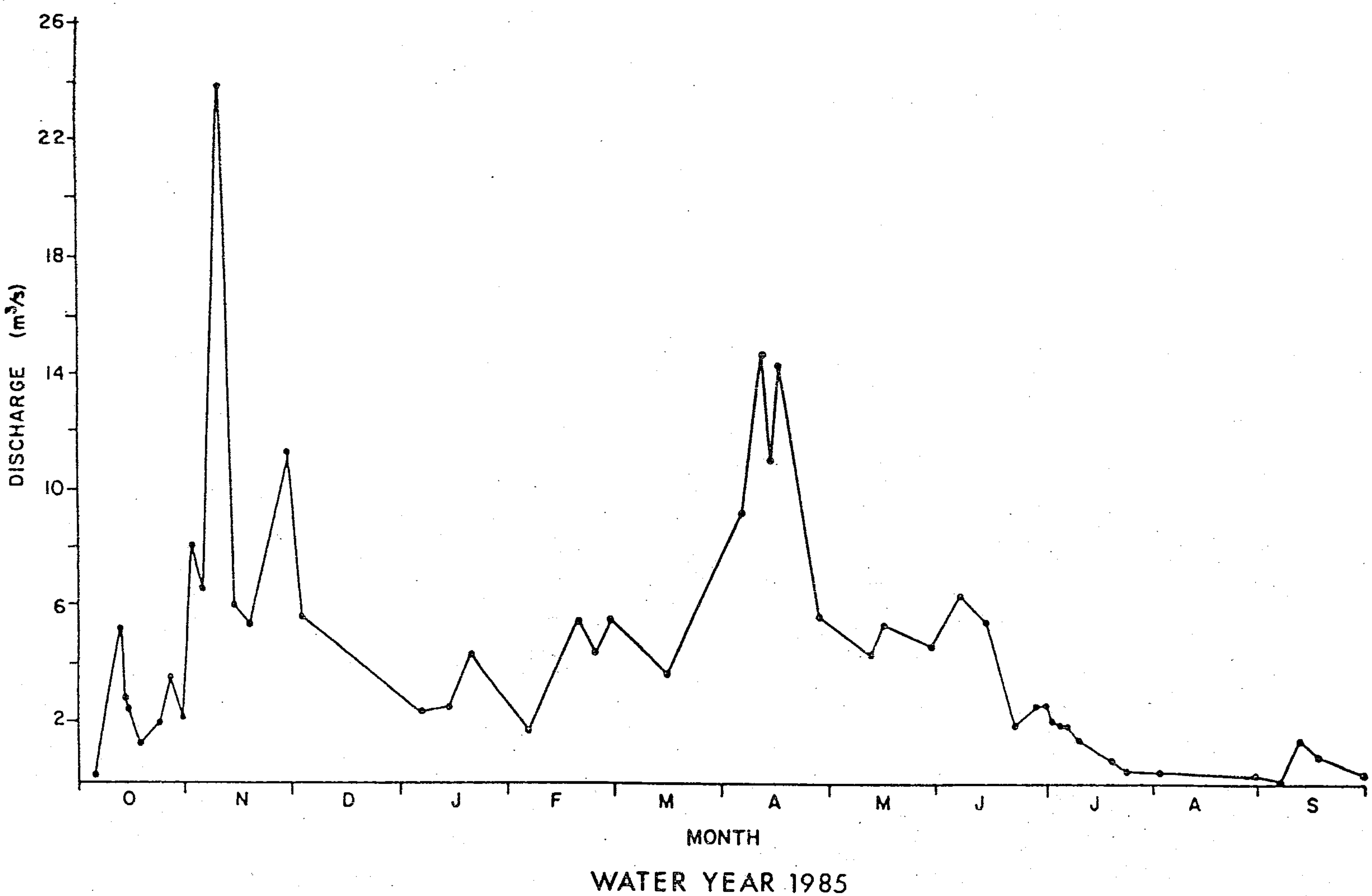

Figure 7. Hydrograph for water year 1985, Canyon Creek, Trinity County, California.

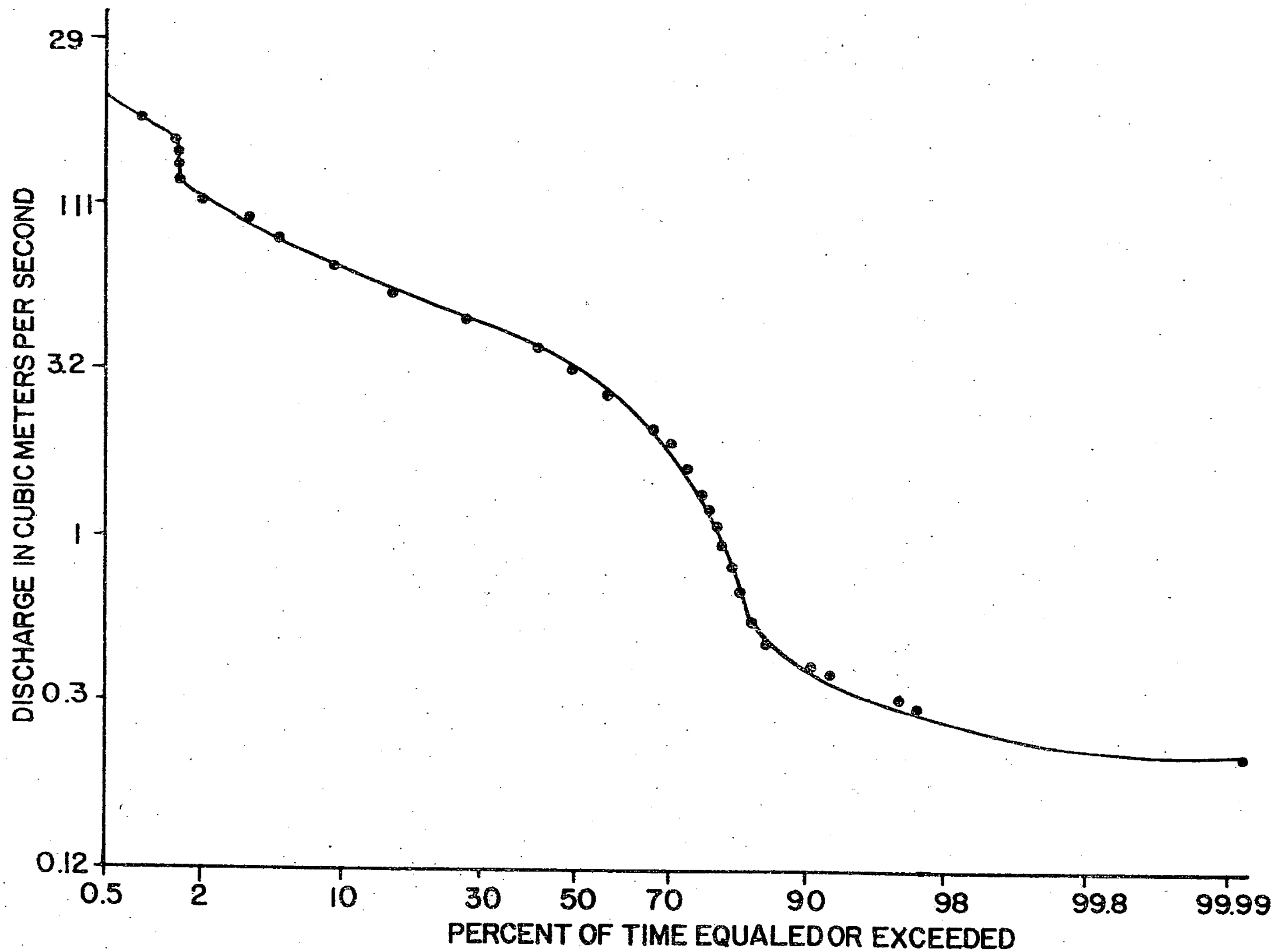

Figure 8. Flow duration curve for water year 1985, Canyon Creek, Trinity County, California.

height, wetted perimeter, mean depth, and mean velocity changed with discharge at each gaging station (Figures 9, 10 and 11). The net x-sectional area changed +0.23, -0.04 and -0.07 m^2 at x-section 1, 2 and 3 respectively (Table 5, Figures 12, 13 and 14). Streambed particle size, embeddedness, gradient, and sinuosity for each cross-section are presented (Table 5). Estimated bankfull channel dimensions are presented in Table 6.

Water quality parameters were measured at four sampling stations in Canyon Creek and are summarized by station (Tables 7, 8, 9 and 10). Turbidities rarely exceeded 1 NTU. Suspended sediment load was usually 0 to 1 mg/l. Minimum water temperature occurred in April and maximum in August 1985, at water sampling station 1 (Figure 15).

Dredge Impacts

The localized dredging impacts on the stream channel, fish habitat and steelhead fry numbers were measured before and after dredging at two operations in Canyon Creek in 1985. Water quality and sediment deposition were measured during dredging at both sites. At upper dredge (site 1) a 12.7 cm aperature dredge was operated for approximately 75 hours from June 25 to August 25; at lower dredge (site 2) a 10.16 cm aperature dredge was operated for approximately 28 hours from July 25 to September 15 (Figure 3).

At site 1, transects 4 and 9 m below dredge accumulated enough dredge tailings to reduce the channel's x-sectional areas by 0.77 and 1.29 m^2, respectively (Figure 16). At transects 3 through 6 (16 to 49 m below dredge) only slight changes in x-sectional area occurred. At the control transect above dredge, the x-sectional area increased 0.41 m^2. Deposited sediment (<2 mm) at 9 m below dredge was 42,366 $g/m^2/day$, deposition dropped to about 1175 $g/m^2/day$ at 16 amd 25 m below dredge (Table 11). Sediment deposition was 22 $g/m^2/day$ above dredge. Geometric mean particle diameter changed from pre-dredging size along all transects below the dredge. The most significant were

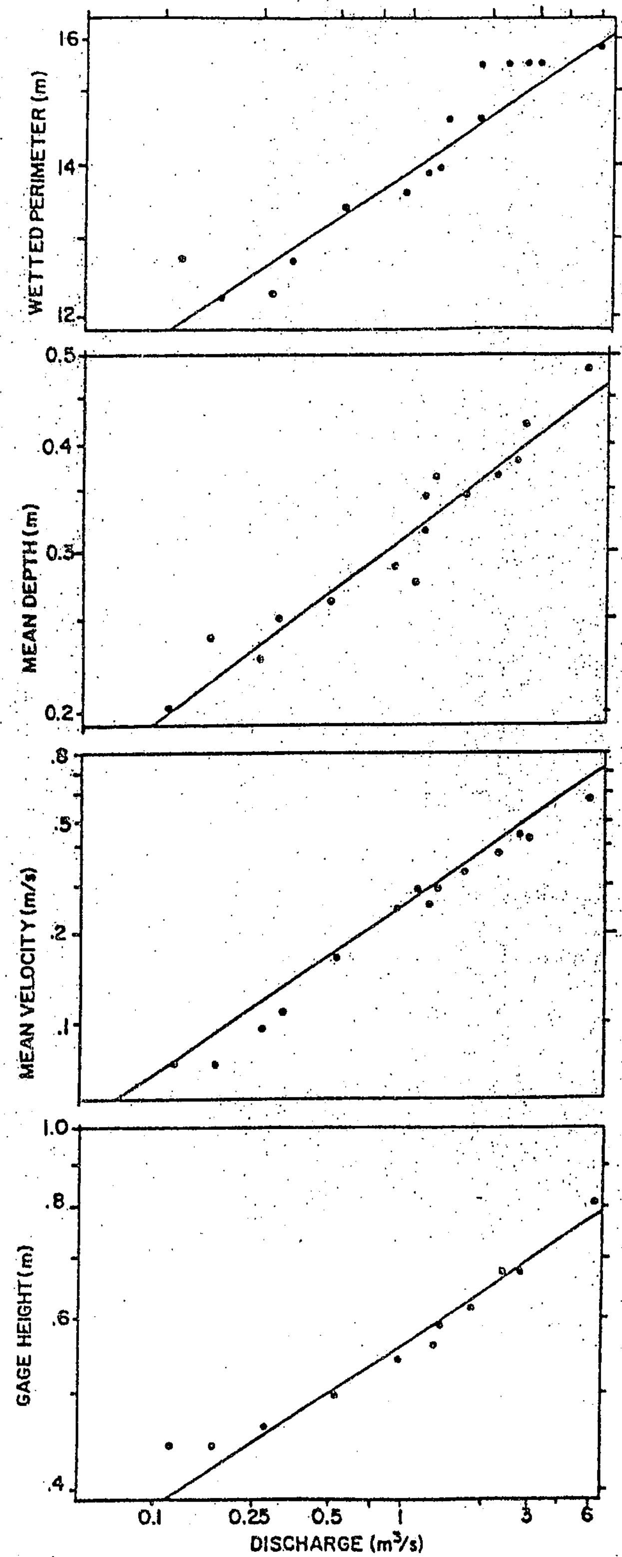

Figure 9. Stream discharge in water year 1985 and stream variables at cross section 1, Canyon Creek, Trinity County, California.

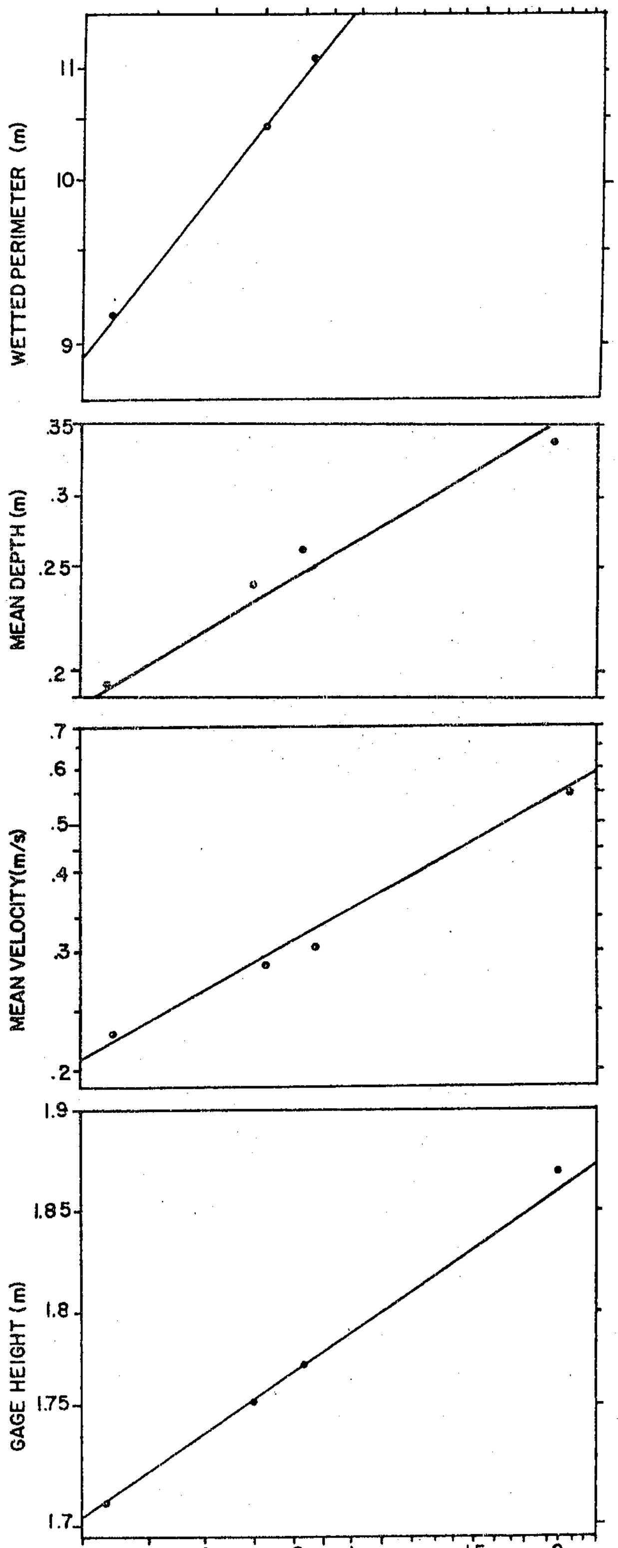

Figure 10. Stream discharge in water year 1985 and stream variables at cross section 2, Canyon Creek, Trinity County, California.

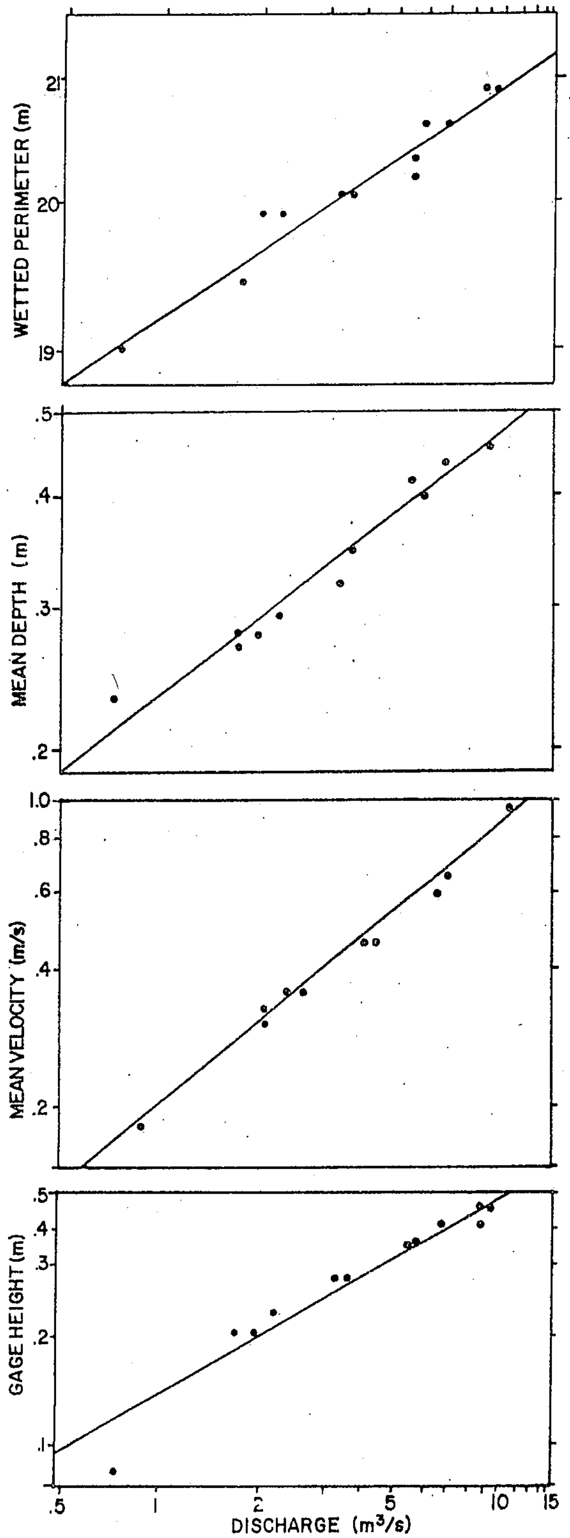

Figure 11. Stream discharge in water year 1985 and stream variables at cross section 3, Canyon Creek, Trinity County, California.

Table 5. Stream channel parameters for Canyon Creek, Trinity County, California, 1985.

	Cross Section 1	2	3
Distance from mouth (km)	2.0	8.0	22.0
Elevation (m)	457.0	564.0	896.0
Gradient (%)	0.5	1.3	2.3
Sinuosity	1.18	1.25	1.14
Geometric mean particle diameter (mm)	35.0	54.0	70.0
Embeddedness (%)	20.0	7.5	1.0
Aggradation[a] (m^2)	0.29	0.55	0.72
Degradation[a] (m^2)	0.52	0.51	0.65
Net change[a] (m^2)	+0.23	-0.04	-0.07

[a]From July-September 1984 to July 1985.

Table 6. Estimated bankfull parameters for Canyon Creek, Trinity County, California, 1985.

	Cross section 1	2	3
Discharge (m^3/s)	23.8	18.3	15.9
Cross-sectional area (m^2)	23.5	9.6	11.2
Width (m)	27.8	16.1	14.2
Wetted perimeter (m)	29.3	17.1	16.5
Mean depth (m)	0.84	0.60	0.76
Mean velocity (m/s)	1.01	1.91	1.42
Manning's n	0.034	0.043	0.089

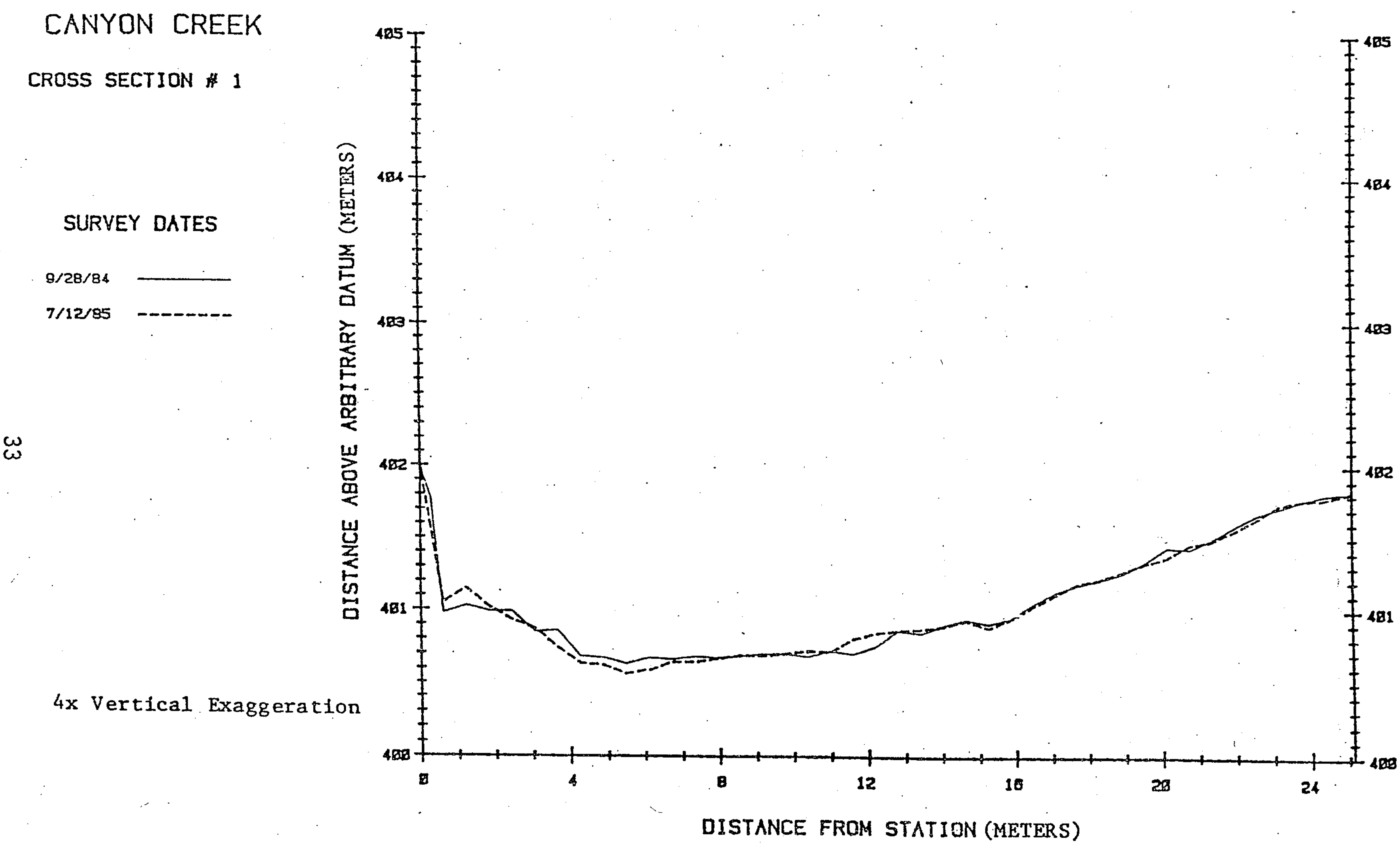

Figure 12. Stream contour change at cross section 1, Canyon Creek, Trinity County, California.

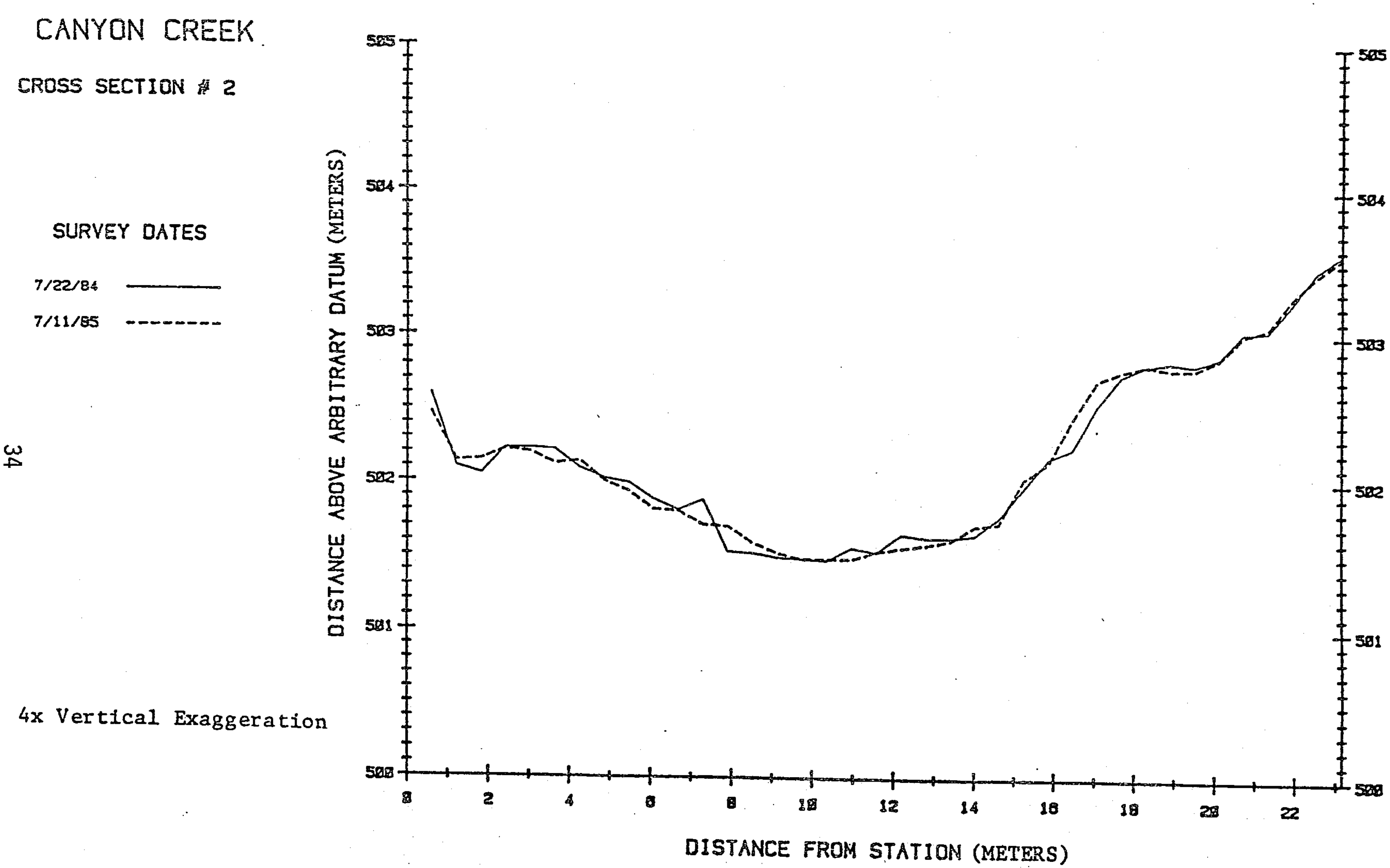

Figure 13. Stream contour change at cross section 2, Canyon Creek, Trinity County, California.

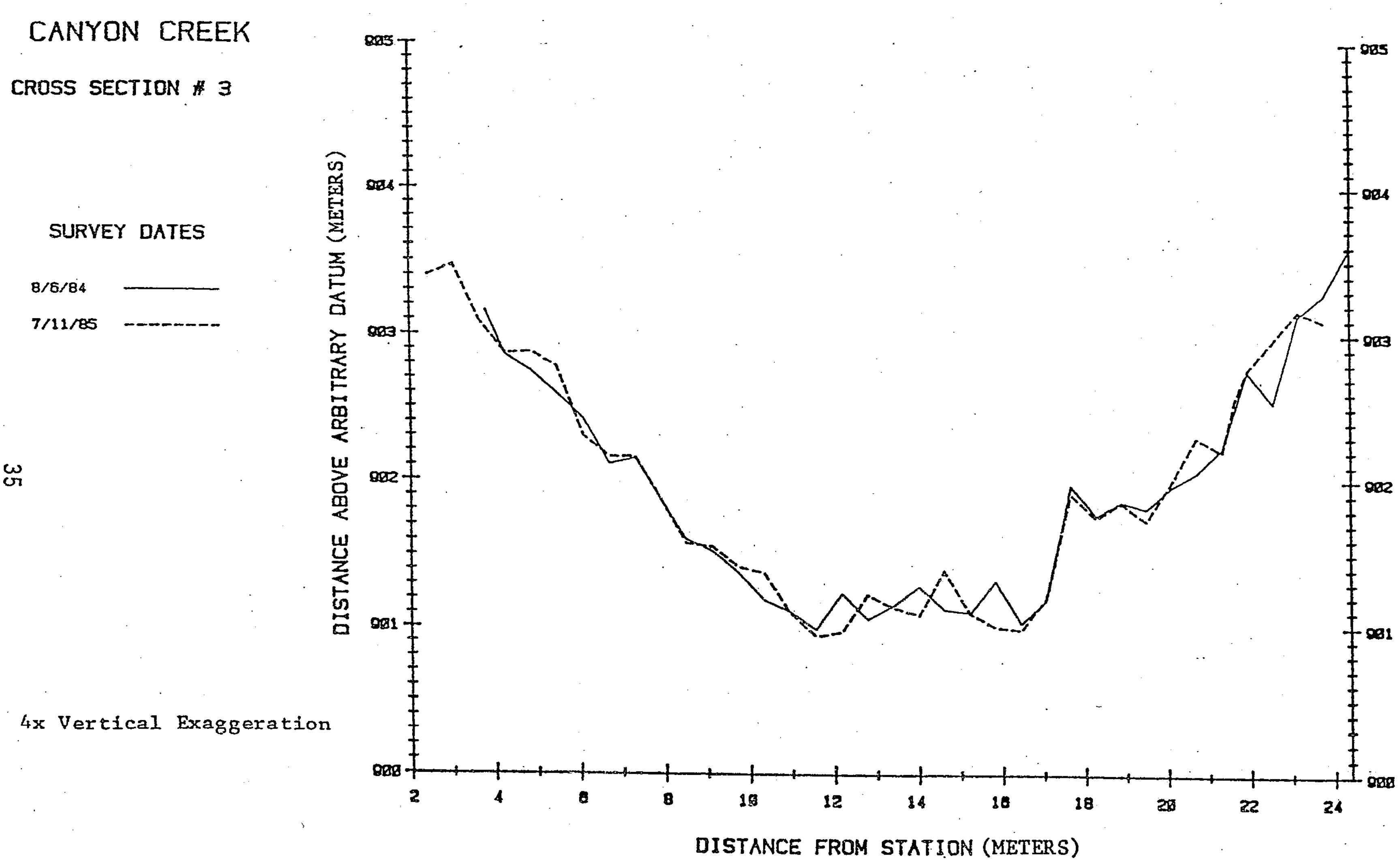

Figure 14. Stream contour change at cross section 3, Canyon Creek, Trinity County, California.

Table 7. Water quality parameters at site 1, Canyon Creek, Trinity County, California.

Date	Temperature (C°)	Turbidity (NTU)	Conductivity (µmho)	Suspended sediment (mg/l)	Total dissolved solids (mg/l)
02/16/84	3	0.28	T		
09/07/84	20	0.23	58		
09/10/84	19	0.21	60		
09/14/84	17	0.32	68		
09/15/84	18	0.29	60		
10/05/84	15	1.20	66	4	44
10/14/84	11	0.32	T		
10/19/84	9	0.39	60		
11/03/84	8	0.80	T		
12/02/84	6	0.52	80		
01/06/85	5	0.21	57		
02/05/85	3	0.23	68		
02/19/85	6	0.32	50		
03/19/85	6	0.20	52		
04/05/85	9	0.93	T	6	6
04/14/85	9	0.80	25		
05/13/85	13	0.56	34	3	
05/29/85	11	0.27	29	0	
06/08/85	14	1.30	19.5	6	15
06/26/85	18	0.55	T		
07/03/85	18	0.48	T		
07/19/85	23	0.44	49	0	
08/07/85	20	0.48	62	0	
08/29/85	19	1.00	91.5	1	
09/17/85	18	0.68	52		

Table 8. Water quality parameters at site 2, Canyon Creek, Trinity County, California.

Date	Temperature (C°)	Turbidity (NTU)	Conductivity (μmho)	Suspended sediment (mg/l)	Total dissolved solids (mg/l)
09/15/82	17				
02/19/83	6	2.4	80		
03/05/83	8	2.2	70		
03/27/83	7	2.3	75		
04/02/83	7	3.2	70		
04/10/83	7	0.93	65		
04/16/83	8	0.65	65		
05/07/83	8	0.82	50		
05/14/83	9	0.63	50		
06/22/83	11	0.92	T		
07/07/83	10	1.5	T		
07/22/83	14	0.69	T		
08/03/83	15	0.85	T		
08/10/83	15	0.95	T		
08/20/83	15	0.68	T		
09/01/83	12	0.72	T		
09/19/83	16	2.6	T		
10/04/83	15	0.82	T		
10/08/83	14	0.49	T		
11/12/83	7	1.3	T		
07/19/84	18	0.49	T		
07/20/84	19	21.0[a]	T		
07/22/84	19	0.52	T		
07/27/84	19	0.44	T		
09/05/84	19	0.34	55		
09/07/84	19	0.46	65		
09/10/84	20	0.28	53		
09/12/84	18	0.27	65		
09/15/84	18	0.27	68		
10/05/84	14	2.70	79	3	35
10/14/84	11	0.42	T		
10/19/84	9	0.53	57		
11/03/84	7	0.59	T		
12/02/84	6	0.48	76		
01/06/85	5	0.19	70		
02/05/85	4	0.24	50		
02/19/85	7	0.23	62		
03/19/85	7	0.36	50		
04/05/85	8	0.74	34	6	60
04/14/85	10	0.50	26		
05/13/85	12	0.42	33	2	
05/29/85	11	0.97	27	1	
06/08/85	15	1.60	24	3	47
06/26/85	19	0.61	T		
07/03/85	18	0.50	T		
07/19/85	22	0.49	47	0	
08/07/85	19	0.67	64	0	
08/29/85	18	1.00	65	2	
09/17/85	18	0.68	52		

[a]Private road maintenance 300 meters upstream from sampling site.

Table 9. Water quality parameters at site 3, Canyon Creek, Trinity County, California.

Date	Temperature (C°)	Turbidity (NTU)	Conductivity (µmho)	Suspended sediment (mg/l)	Total dissolved solids (mg/l)
02/16/84	2	0.16	T		
08/29/84	19	0.34	T		
09/05/84	18	0.22	50		
09/06/84	17	0.23	50		
09/07/84	17	0.19	50		
09/10/84	18	0.25	T		
09/12/84	16	0.24	51		
09/15/84	16	0.29	57		
10/05/84	13	0.15	64		
10/14/84	10	0.24	T		
10/19/84	9	0.18	50		
11/03/84	6	0.53	T		
12/02/84	6	0.43	75		
01/06/85	5	0.27	55		
02/05/85	4	0.19	55		
02/19/85	6	0.22	55		
03/19/85	8	0.49	T		
04/05/85	8	0.71	35	7	0
04/14/85	9	0.48	24		
05/13/85	11	0.27	28	0	
05/29/85	9	0.34	23	1	
06/08/85	14	0.50	20	1	0
06/26/85	17	0.39	T		
07/03/85	18	0.33	T		
07/19/85	22	0.36	26	0	
08/07/85	19	0.55	56	0	
08/29/85	15	1.10	65	2	
09/17/85	11	0.42	T		

Table 10. Water quality parameters at site 4, Canyon Creek, Trinity County, California.

Date	Temperature (C°)	Turbidity (NTU)	Conductivity (µmho)	Suspended sediment (mg/l)	Total dissolved solids (mg/l)
02/19/83	4	0.04	55		
03/05/83	5	0.75	T		
03/27/83	3	0.22	T		
04/02/83	4	0.42	T		
04/10/83	4	0.40	T		
04/16/83	4	0.22	T		
05/07/83	6	0.47	T		
05/14/83	7	0.28	T		
06/22/83	9	0.14	T		
07/07/83	7	0.27	T		
07/22/83	8	0.15	T		
08/03/83	11	0.13	T		
08/10/83	13	0.14	T		
08/20/83	12	0.12	T		
09/01/83	9	0.16	T		
09/19/83	13	0.13	T		
10/04/83	13	0.14	T		
10/16/83	9	0.11	T		
11/12/83	6	0.19	T		
02/16/84	2	0.28	T		
09/07/84	16	0.18	T		
09/10/84	17	0.25	T		
09/12/84	15	0.13	T		
09/15/84	16	0.17	T		
10/05/84	13	0.16	T		
10/14/84	9	0.19	T		
10/19/84	8	0.14	T		
11/03/84	6	0.42	T		
12/02/84	4	0.19	T		
01/06/85	4	0.19	T		
02/05/85	3	0.17	T		
02/19/85	4	0.22	T		
03/19/85	7	0.21	T		
04/05/85	6	0.53	18	4	35
04/14/85	9	0.42	13		
05/13/85	8	0.24	16	0	
05/29/85	4	0.25	13	0	
06/08/85	12	0.37	12	3	6
06/26/85	14	0.29	T		
07/13/85	16	0.29	T		
07/19/85	19	0.39	20	0	
08/07/85	16	0.44	26	0	
08/29/85	14	0.65	T	0	
09/17/85	11	0.43	T		

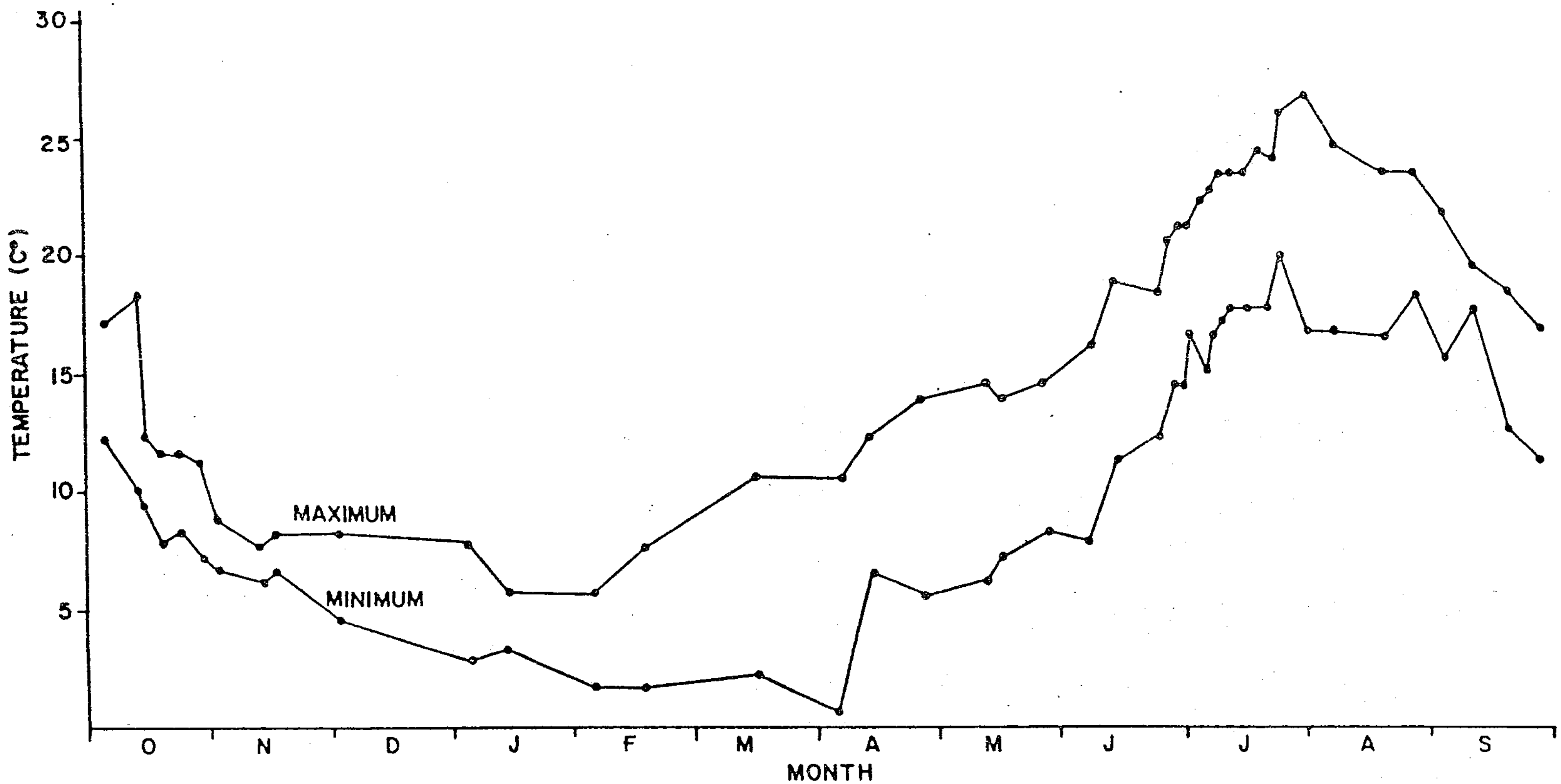

Figure 15. Water temperature at lower water quality station during water year 1985, Canyon Creek, Trinity County, California.

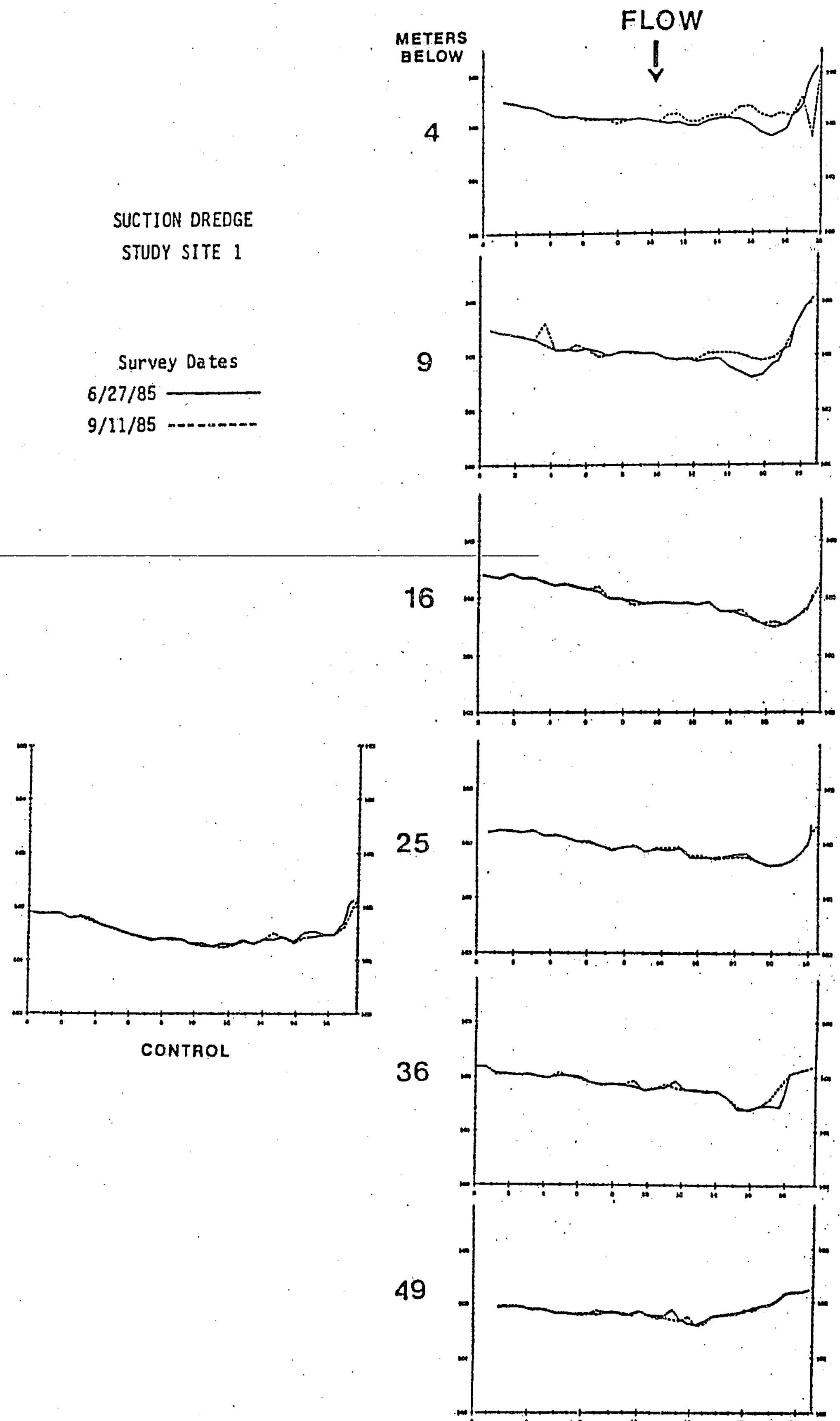

Figure 16. Stream contour change below dredge at lower dredge site, Canyon Creek, Trinity County, California.

Table 11. Stream parameters at upper dredge (site 1), Canyon Creek, Trinity County, California. 5" dredge

	Above dredge	Transect (below dredge) 1	2	3	4	5	6
Distance from dredge (m)	708	4	9	16	25	36	49
X-sectional area net change (m^2)	+0.41	-0.77	-1.29	-0.08	+0.05	-0.26	+0.29
Deposited sediment[b] (g/m^2/day)	22	-	42,366	1154	1207	-	-
Geometric mean particle diameter (mm)							
Pre-mining	38.5	66.4	76.2	36.5	45.6	32.4	47.7
Post-mining	44.1	17.1	27.7	19.1	33.1	26.6	43.9
Embeddedness (%)							
Pre-mining	26	21	12	21	33	44	31
Post-mining	30	51	43	51	48	70	46
Suspended sediment (mg/l)	0	244.0	31.5	22.0	14.5	16.5	11.5
Turbidity (NTU)	0.47	20.50	5.80	4.80	3.75	4.05	3.35
Steelhead young-of-year/30m stream length							
Pre-mining	95	-	-	-	137	-	-
Post-mining	72	-	-	-	94	-	-

[a]A 12.7 cm suction dredge operated approximately 75 hours from June 25 to August 25, 1985.

[b]Three silt traps per transect were subject to 2.5 hours of dredge activity.

reductions of 74% and 64% at 4 and 9 m, respectively, below the dredge. Changes in particle size diminished with increasing distance downstream. Substrate particle size increased by 13% above dredge. After dredging, embeddedness of the substrate had increased along all transects below and above dredge. Increased embeddedness was highest at 4, 9, 16 and 25 m below dredge. During dredging, suspended sediment and turbidity were high immediately below dredge, but diminished rapidly with distance downstream. Suspended sediment varied from 244 mg/l at 4 m below dredge to 11.5 mg/l at 49 m below (Table 11). No suspended sediment was measurable in the water column above dredge. Turbidity varied from 20.5 NTU 4 m below the dredge to 3.4 NTU at 49 m below. Turbidity measured 0.5 NTU above dredge. Dredge mining did not effect stream temperature at site 1. The numbers of steelhead young-of-the-year declined 31% below dredge and 24% above from the pre-dredging total.

At site 2, channel x-sectional area at 4 m below dredge was reduced 1.19 m^2 by the accumulation of dredge tailings (Figure 17). At transects 9 to 49 m below dredge and above dredge only slight changes in area occurred. Sediment (<2 mm) deposited below the dredge declined from 12,080 g/m^2/day 4 m below dredge to 285 g/m^2/day 25 m below. Above dredge, 105 g/m^2/day of sediment were deposited (Table 12). After dredging, geometric mean particle diameter was reduced 82%, 42% and 13% at 4 m, 9 m and 36 m, respectively, below dredge. A 1% change occurred above dredge. Embeddedness of the substrate increased from 9% to 14% below dredge and 6% above after dredging. Suspended sediment was 47.5 mg/l 4 m below dredge and 4.0 mg/l 49 m below (Table 12). Suspended sediment above dredge was 0.5 mg/l. Turbidity was 5.6 NTU 4 m below dredge and 2.9 NTU 49 m below. Turbidity was 0.9 NTU above dredge. Temperature was not influenced by dredging at site 2. The number of steelhead young-of-the-year declined 14% below dredge and 13% above dredge from pre-dredging numbers.

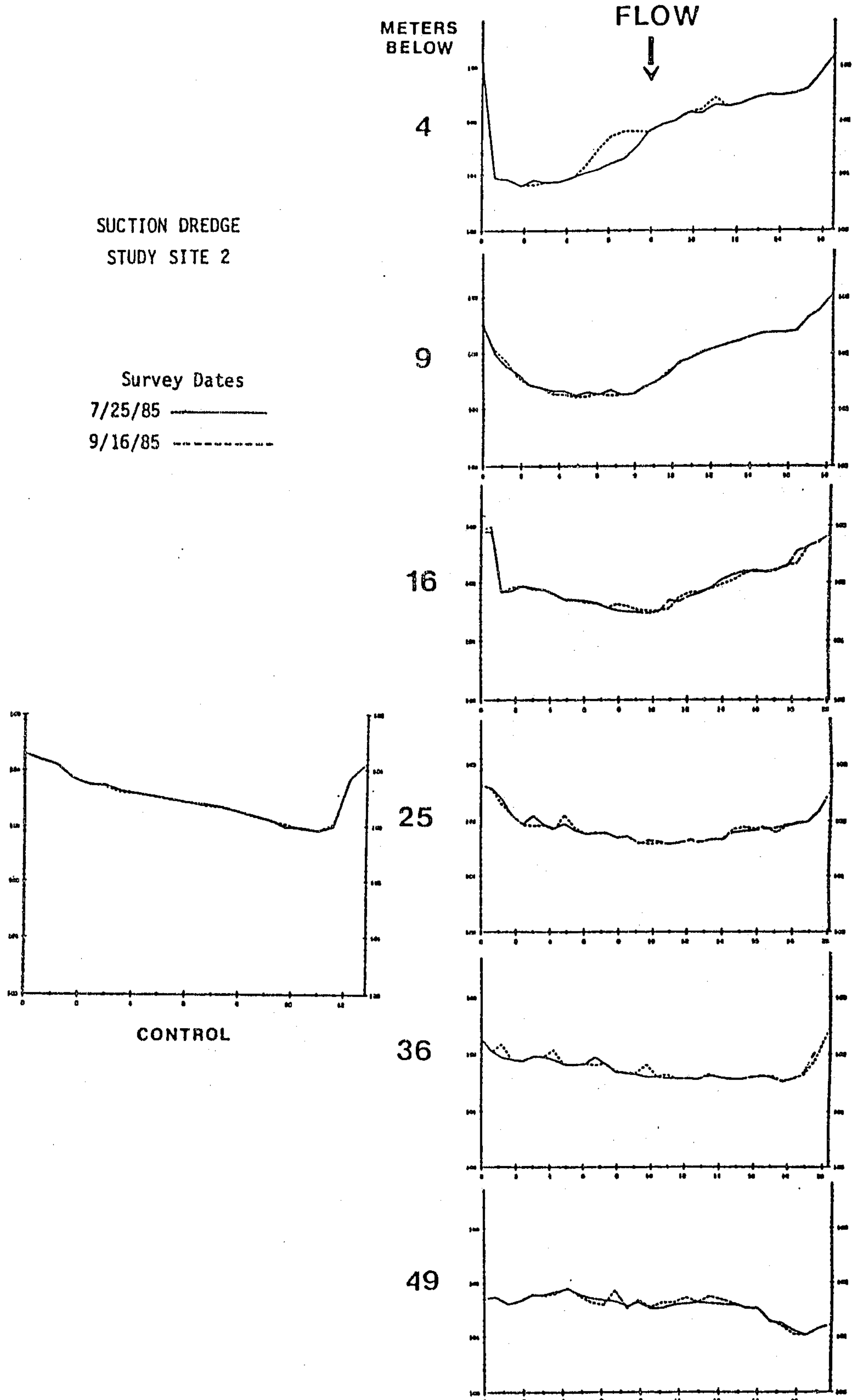

Figure 17. Stream contour change below dredge at lower dredge site, Canyon Creek, Trinity County, California.

Table 12. Stream parameters at lower dredge (site 2), Canyon Creek, Trinity County, California. 4" dredge

	Above dredge	Transect (below dredge) 1	2	3	4	5	6
Distance from dredge (m)	76	4	9	16	25	36	49
X-sectional area net change (m^2)	+0.03	-1.19	+0.07	-0.07	+0.17	-0.30	-0.28
Deposited sediment[b] (g/m^2/day)	105	12,080	671	361	285	-	-
Geometric mean particle diameter (mm)							
Pre-mining	44.9	34.3	30.6	46.0	65.3	53.9	60.8
Post-mining	44.3	6.2	17.6	30.1	56.7	46.4	40.1
Embeddedness (%)							
Pre-mining	31	57	54	42	36	34	26
Post-mining	37	66	66	55	47	47	40
Suspended sediment (mg/l)	0.5	47.5	14.0	7.5	4.5	6.5	4.0
Turbidity (NTU)	0.88	5.60	3.65	2.70	3.45	4.00	2.85
Steelhead young-of-year/30 m length stream							
Pre-mining	119	-	-	103	-	-	-
Post-mining	102	-	-	90	-	-	-

[a]A 10.16 cm suction dredge operated approximately 28 hours from July 25 to September 15, 1985.

[b]Three silt traps per transect were subject to 2.5 hours of dredge activity.

Salmonids

Distribution of anadromous salmonids in the Canyon Creek Basin is restricted by natural and man-made barriers. Freese (1980) identified a log and boulder barrier that blocks migration of salmonids 1.5 km upstream of Globe Mill. Most tributaries are either too steep to allow salmonid passage, or are blocked by culverts where the Canyon Creek road crosses them. Clear Gulch appears to be the most productive tributary accessable to salmonids.

Steelhead Food Habits

The diet of age 0, 1, and 2 steelhead were determined from stomach contents. Diet of all three steelhead age classes differed with the stream section sampled. Juvenile steelhead fed on larger aquatic invertebrates and fish, while young of year fed on smaller aquatic invertebrates. Age-0 steelhead fed on Chironomidae, Heptageniidae, and Baetis sp. at all areas of Canyon Creek (Table 13). Simuliidae were common food items at mid stream sites, while Helicopsyche sp. and Hydroptila sp. were common food items in lower stream sites. Terrestrial insects were not a common food item for age-O steelhead. Age-1 steelhead fed on Chironomidae and Baetidae at all sites (Table 14). Heptageniidae and Perlodidae were common food items at upper stream sites, while Simuliidae, Salmonidae, and Rhyacophila sp. were important food items at mid stream sites. At the lower stream sites, Perlidae and Glossosomatidae were important food items. Hydropsyche sp. was a common food item for age-1 fish at lower and mid stream sites, and terrestrial insects were present in the diet at all sites. Age-2 steelhead had a more diverse diet at the upper stream than at lower and mid stream sites; however, this may have been a result of small sample size. Larger aquatic invertebrates such as Orohermes crepusculus, Perlinodes sp., and Perlidae composed a greater proportion of diet volumetrically and lower numerically than other food items (Table 15). Age-2 steelhead commonly fed on Baetis sp.

Table 13. Stomach contents of age-0 steelhead in September 1982, by number and volume (x0.001 ml) and standard deviation (SD) Canyon Creek, Trinity County, California. Lower stream, stations 1 and 2; mid-stream, stations 4, 5 and 6; upper stream, stations 8 and 9.

	Number of stomachs											
	Lower stream (10)				Mid stream (9)				Upper stream (10)			
Food item	No	SD	Vol	SD	No	SD	Vol	SD	No	SD	Vol	SD
Coleoptera:												
Corixidae *Sigma* sp	0.1	0.3	0.1	0.3	-	-	-	-	-	-	-	-
Elmidae *Rhizelmus* sp	-	-	-	-	-	-	-	-	0.2	0.6	0.2	0.6
Diptera:												
Blephariceridae *Blepharicera* sp	0.1	0.3	0.1	0.3	-	-	-	-	-	-	-	-
Chironomidae (larvae)	6.2	5.9	6.8	5.8	7.7	4.9	8.2	4.5	30.8	24.6	30.8	24.6
Chironomidae (pupae)	0.8	0.9	0.8	1.5	-	-	-	-	0.7	0.9	0.7	0.9
Empididae *Chelifera* sp	-	-	-	-	1.6	3.6	4.9	9.2	-	-	-	-
Simuliidae *Simulium* sp	-	-	-	-	19.4	24.9	38.9	49.7	-	-	-	-
Tipulidae *Pedicia* sp	0.1	0.3	T	T	-	-	-	-	-	-	-	-
Ephemeroptera:												
Baetidae *Baetis* sp	2.5	3.1	7.5	9.2	8.4	10.0	25.3	30.3	6.1	11.7	18.3	35.2
Ephemerellidae *Drunella* sp	-	-	-	-	-	-	-	-	0.7	0.9	2.8	1.8
Heptageniidae	0.3	0.5	1.1	2.0	0.8	2.0	3.2	7.0	0.6	0.8	1.8	2.5
Siphlonuiidae *Ameletus* sp	0.1	0.3	0.3	0.9	-	-	-	-	-	-	-	-
Lepidoptera:												
Pyralidae *Crambus* sp	0.1	0.3	0.5	1.6	-	-	-	-	-	-	-	-
Plecoptera:												
Chloroperlidae *Sweltza* sp	-	-	-	-	0.1	0.3	1.1	3.3	-	-	-	-
Nemouridae *Zapada* sp	0.1	0.3	0.3	0.9	0.1	0.3	0.3	1.0	-	-	-	-
Perlodidae	-	-	-	-	0.1	0.3	0.3	0.8	0.2	0.4	0.2	0.4
Trichoptera:												
Brachycentridae	0.8	2.2	0.8	2.2	-	-	-	-	0.2	0.4	T	T
Glossosomatidae *Glossosoma* sp	-	-	-	-	0.1	0.3	0.4	1.3	-	-	-	-
Helicopsychidae *Helicopsyche* sp	2.5	4.6	5.0	2.2	0.1	0.3	0.2	0.7	-	-	-	-
Hydropsychidae *Hydropsyche* sp	-	-	-	-	1.0	1.4	4.0	5.7	0.1	0.3	0.4	1.3
Hydroptilidae *Hydroptila* sp	2.3	2.6	2.3	2.6	0.2	0.5	0.2	0.5	0.1	0.3	0.1	0.3
Limnephilidae *Ecclisomyia* sp	-	-	-	-	-	-	-	-	0.1	0.3	0.9	2.8
Philopotamidae *Dolophilodes* sp	-	-	-	-	0.1	0.3	1.1	3.3	-	-	-	-
Polycentropodidae Polycentropus	-	-	-	-	0.1	0.3	0.3	1.0	-	-	-	-
Rhyacophilidae *Rhyacophila* sp	-	-	-	-	0.2	0.6	2.4	7.3	-	-	-	-
Aquatic Insect Total:	15.9	8.8	25.5	13.6	40.3	36.1	93.6	79.4	39.8	24.5	55.7	36.3
Terrestrial Insect Total:	0.2	0.6	0.5	1.6	-	-	-	-	-	-	-	-
Unidentified:			24.0	21.2			18.9	25.2			21.0	29.6

Table 14. Stomach contents of age-1 steelhead in September 1982, by number and volume (x0.001 ml) and standard deviation (SD) Canyon Creek, Trinity County, California. Lower stream, stations 1 and 2; mid-stream stations 4, 5 and 6; upper stream, stations 8 and 9.

	Number of stomachs											
	Lower stream (7)				Mid stream (10)				Upper stream (7)			
Food item	No	SD	Vol	SD	No	SD	Vol	SD	No	SD	Vol	SD
Coleoptera:												
Elmidae	0.1	0.4	0.1	0.4	-	-	-	-	0.6	1.5	1.1	3.0
Diptera:												
Chironomidae (larvae)	4.6	4.5	4.6	4.5	1.0	1.2	1.0	1.2	8.1	8.8	8.1	8.8
Chironomidae (pupae)	1.1	1.9	1.1	1.9	0.3	0.9	0.3	0.9	1.9	4.9	1.9	4.9
Dixidae Dixa sp	-	-	-	-	0.1	0.3	0.1	0.3	-	-	-	-
Simuliidae Simulium sp	-	-	-	-	1.7	1.8	3.4	3.5	0.1	0.4	0.3	0.8
Ephemeroptera:												
Baetidae Baetis sp	1.0	0.8	3.0	2.4	4.4	8.2	12.0	23.5	10.0	10.2	29.7	30.1
Ephemerellidae Drunella sp	-	-	-	-	-	-	-	-	0.1	0.4	0.3	0.8
Heptogeniidae	0.1	0.4	0.4	1.1	0.6	1.3	11.0	12.8	2.4	5.6	7.7	17.8
Siphlonuridae Ameletus sp	-	-	-	-	-	-	-	-	0.1	0.4	0.4	1.1
Plecoptera:												
Chloroperiidae Sweltza sp	-	-	-	-	0.1	0.3	1.0	3.2	-	-	-	-
Nemouridae Malenka sp	-	-	-	-	0.1	0.3	0.2	0.6	-	-	-	-
Peltoperlidae	-	-	-	-	0.1	0.3	1.0	3.2	0.1	0.4	14.3	37.8
Perlidae	0.6	1.5	114.5	303.9	0.1	0.3	21.0	66.4	0.1	0.4	3.4	9.1
Perlodidae Perlinodes sp	-	-	-	-	0.9	2.2	10.8	26.8	0.6	1.1	6.9	13.6
Trichoptera:												
Brachycentridae	0.3	0.5	0.3	0.5	-	-	-	-	0.1	0.4	0.1	0.4
Glossosomatidae	1.0	1.7	10.0	17.3	0.1	0.3	0.4	1.3	-	-	-	-
Helicopsychidae Helicopsyche sp	0.3	0.5	0.6	1.0	-	-	-	-	-	-	-	-
Hydropsychidae Hydropsyche sp	0.6	1.0	2.3	3.9	0.5	1.0	2.0	3.9	-	-	-	-
Hydroptilidae Hydroptila sp	0.3	0.8	0.3	0.8	0.7	0.9	0.7	0.9	0.3	0.8	0.3	0.8
Rhyacophilidae Rhyacophila sp	-	-	-	-	0.4	0.7	4.4	7.7	-	-	-	-
Aquatic Insect Total:	10.0	6.3	137.6	312.3	10.8	12.2	64.4	100.7	24.9	17.0	74.6	47.1
Terrestrial Insect Total:	0.1	0.4	0.7	1.9	0.2	0.6	0.1	0.3	0.4	1.1	4.3	11.3
Salmonidae:	-	-	-	-	0.1	0.3	35.0	110.7	-	-	-	-
Unidentified:			130.0	91.5			128.0	123.5			64.3	45.4

Table 15. Stomach contents of age-2 steelhead in September 1982, by number and volume (x0.001 ml) and standard deviation (SD) Canyon Creek, Trinity County, California. Lower stream, stations 1 and 2; mid-stream, stations 4, 5 and 6; upper stream, stations 8 and 9.

Food item	Number of stomachs											
	Lower stream (4)				Mid stream (3)				Upper stream (10)			
	No	SD	Vol	SD	No	SD	Vol	SD	No	SD	Vol	SD
Coleoptera:												
Elmidae	0.8	1.5	1.2	3.5	-	-	-	-	0.2	0.4	3.2	9.8
Diptera:												
Chironomidae (larvae)	-	-	-	-	-	-	-	-	4.3	7.8	4.6	8.1
Chironomidae (pupae)	-	-	-	-	-	-	-	-	6.5	10.1	6.3	10.2
Simuliidae Simulium sp	-	-	-	-	-	-	-	-	0.1	0.3	0.2	0.6
Ephemeroptera:												
Baetidae Baetis sp	-	-	-	-	0.3	0.6	1.0	1.7	10.2	9.2	30.6	27.5
Ephemerellidae Drunella sp	-	-	-	-	-	-	-	-	0.1	0.3	0.2	0.6
Heptageniidae	0.3	0.5	0.8	1.5	-	-	-	-	1.0	1.8	4.7	9.6
Megaloptera:												
Corydalidae Orohermes sp	-	-	-	-	-	-	-	-	0.1	0.3	46.0	145.5
Plecoptera:												
Leuctridae Despaxia sp	-	-	-	-	-	-	-	-	0.1	0.3	0.5	1.6
Nemouridae Zapada sp	-	-	-	-	-	-	-	-	0.1	0.3	0.3	0.9
Perlidae	-	-	-	-	-	-	-	-	0.4	1.3	62.1	196.4
Perlodidae Perlinodes sp	-	-	-	-	-	-	-	-	0.3	0.5	2.6	5.0
Trichoptera:												
Glossosomatidae Glossosoma sp	2.8	3.1	11.0	12.4	-	-	-	-	-	-	-	-
Helicopsychidae Helicopsyche sp	0.3	0.5	0.5	1.0	-	-	-	-	-	-	-	-
Hydropsychidae Hydropsyche sp	-	-	-	-	-	-	-	-	0.1	0.3	0.4	1.3
Hydroptilidae Hydroptila sp	-	-	-	-	-	-	-	-	0.1	0.3	0.1	0.3
Limnephilidae Ecclisomyia sp	-	-	-	-	-	-	-	-	2.0	6.3	18.0	56.9
Rhyacophilidae Rhyacophila sp	0.5	1.0	5.5	11.0	-	-	-	-	0.1	0.3	1.1	3.5
Aquatic Insect Total:	5.0	4.3	30.3	18.7	0.3	0.6	1.0	1.7	25.8	19.8	181.9	376.1
Terrestrial Insect Total:	0.5	1.0	50.0	100.0	-	-	-	-	0.7	1.2	1.6	1.3
Salmonidae:	-	-	-	-	0.3	0.5			-	-	-	-
Unidentified:			213.3	250.0			20.0	34.6			195.5	171.1

and Chironomidae, as did younger steelhead. Terrestrial insects composed a larger part of age-2 steelhead diet than for younger steelhead.

Steelhead Growth and Population Analysis

The length frequencies of steelhead captured in Canyon Creek at all sites in September 1982-1984 are shown in Figure 18. High water during 1983 impaired electroshocking efficiency. We assumed that the 1983 length data accurately reflected the size composition (and resulting growth parameters) of steelhead sampled that year. Steelhead from the 1981 year class were longer at age 1 and 2 than fish from other year classes (Tables 16 and 17). The 1982 year class of steelhead were shorter and weighed less than other year classes at age 0 and 1. Age-2 fish of the 1981 year class were longer and heavier than fish from other year classes (Tables 16 and 18).

The condition factor for steelhead was highest for age-0 and age-1 fish in 1984 and for age-2 fish in 1983 (Table 19). The length-weight relationships for Canyon Creek steelhead by sample year are presented in Figure 19. The curves were determined from preserved fish data. The fish length-scale radius relationships for Canyon Creek steelhead are given in Figure 20. Correlation coefficients for each regression were significant at $P \leq 0.01$.

Population and biomass estimates for steelhead captured in Canyon Creek, September 1982 and 1984, are presented in Tables 20 and 21. Mean weight was corrected for preservation. Population and biomass estimates were not calculated for September 1983 samples because stations could not be accurately sampled due to high water. In 1982, biomass of juvenile steelhead ranged from 3 to 105 kg/ha and in 1984, from 11 to 61 kg/ha.

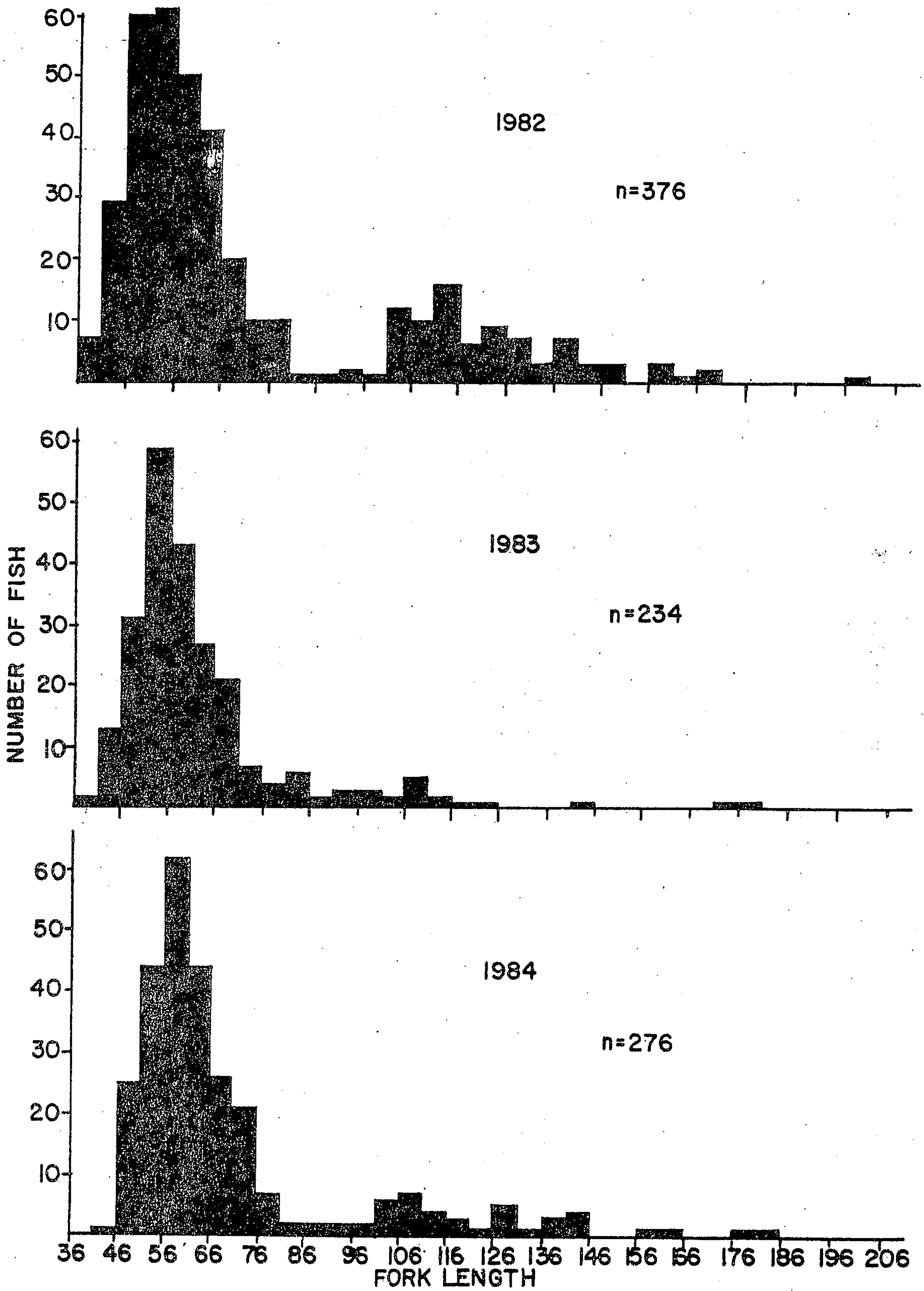

Figure 18. Length frequency of steelhead collected in Canyon Creek, Trinity County, California.

Table 16. Calculated length (mm) of steelhead from Canyon Creek, Trinity County, California.

Year	Year class	Number	Age 1	Age 2
1982	1981	21	67	
	1980	14	58	105
Mean			63	105
S.D.			14	13
1983	1982	14	57	
	1981	3	69	123
Mean			59	123
S.D.			10	11
1984	1983	19	59	
	1982	7	64	110
Mean			61	110
S.D.			13	14

Table 17. Mean length of preserved and mean length corrected for preservation of steelhead captured in September at Canyon Creek, Trinity County, California.

Year	Age	Length (mm)	SD	N
1982	0	56	9	288
	1	114	12	71
	2	152	16	17
1983	0	57	9	211
	1	103	11	20
	2	165	18	3
1984	0	60	8	232
	1	112	15	35
	2	153	19	9
Mean				
Preserved	0	58		731
	1	112		126
	2	153		29
Corrected	0	62		731
	1	116		126
	2	158		29

Table 18. Mean weight of preserved and mean weight corrected for preservation of steelhead captured in September at Canyon Creek, Trinity, County, California.

Year Collected	Age	Weight (g)	SD	N
1982	0	1.9	1.1	288
	1	16.1	6.1	71
	2	36.2	11.4	17
1983	0	2.4	1.4	211
	1	13.3	4.7	20
	2	58.5	18.2	3
1984	0	2.9	1.2	232
	1	18.2	7.4	35
	2	47.0	18.5	9
Mean				
Preserved	0	2.4		731
	1	16.2		126
	2	41.8		29
Corrected	0	2.6		731
	1	18.0		126
	2	43.3		29

Table 19. Condition factor of preserved steelhead captured in September at Canyon Creek, Trinity County, California.

Year Collected	Age	Condition factor	SD	N
1982	0	1.0198	0.1808	288
	1	1.0388	0.1266	71
	2	1.0220	0.1157	17
1983	0	1.1867	0.2292	211
	1	1.2107	0.2126	20
	2	1.2786	0.0137	3
1984	0	1.2679	0.1888	232
	1	1.2490	0.1864	35
	2	1.2482	0.0468	9
Mean	0	1.1467		731
	1	1.1245		126
	2	1.1187		29

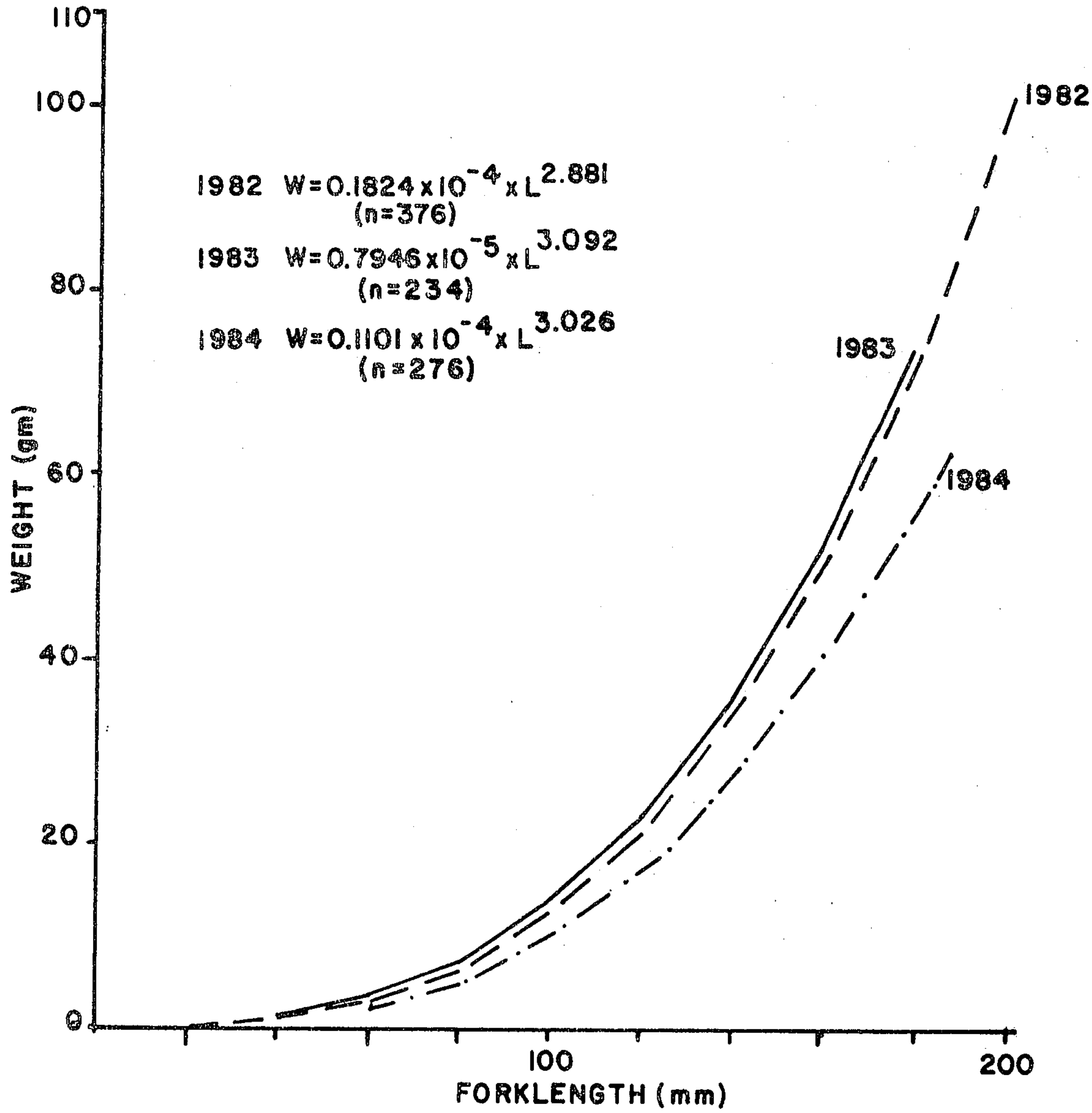

Figure 19. Length-weight relationship of steelhead in September, Canyon Creek, Trinity County, California.

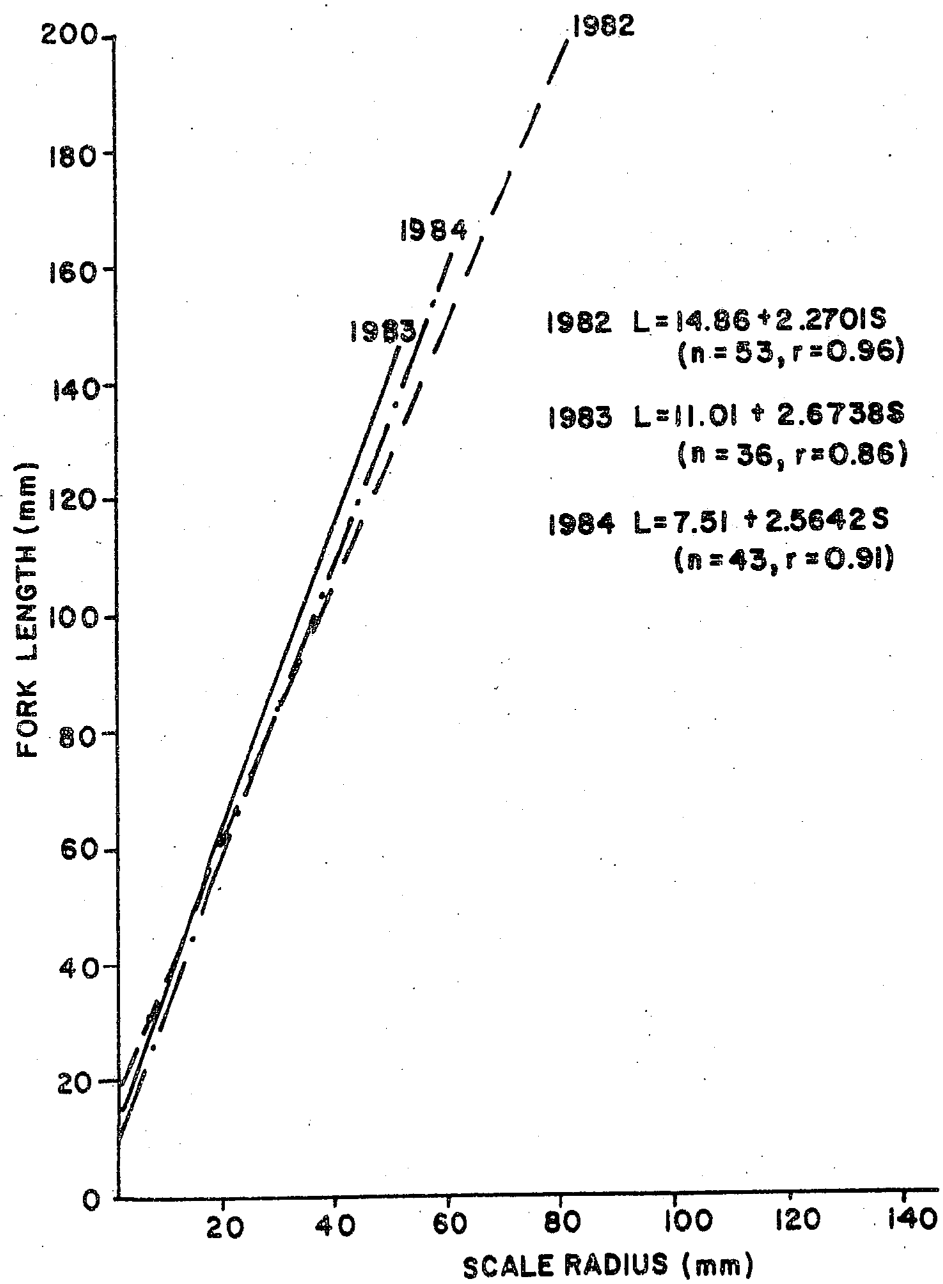

Figure 20. Fish length-scale radius relationship of steelhead in September, Canyon Creek, Trinity County, California.

Table 20. Population estimates and confidence intervals (CI) and biomass estimates for steelhead captured September 15-17, 1982, in Canyon Creek, Trinity County, California. Weight corrected for preservation.

St.	Pop est	95% CI	Mean weight (g)	Biomass (g)	Area (ha)	Biomass (kg/ha)
1	27	9	16.2	437	0.0270	16.2
2	16	10	3.8	61	0.0195	3.1
3	70	50	5.8	406	0.0140	29.0
4	60	8	3.9	234	0.0195	12.0
5 a)	17	3	6.4	109	0.0121	9.0
b)	238	459	6.4	1523	0.0158	96.4
6	350	88	8.1	2835	0.0279	101.6
7	103	14	5.0	515	0.0270	19.1
8	176	22	9.4	1654	0.0205	80.7
9	32	5	17.8	570	0.0167	34.1

Table 21. Population estimates and confidence intervals (CI) and biomass estimates for steelhead captured September 24 and 25, 1984 in Canyon Creek, Trinity County, California. Weight corrected for preservation.

St.	Age	Pop est	95% CI	Mean weight (g)	Biomass (g)	Area (ha)	Biomass (kg/ha)
1	0	46	4	5.1	235	0.0270	8.7
	1	12	12	21.9	263	0.0270	9.7
	2	-	-	49.0	-	0.0270	-
2	0	65	8	5.0	325	0.0298	10.9
	1	-	-	17.7	-	0.0298	-
	2	-	-	-	-	0.0298	-
5	0	199	54	4.6	915	0.0372	24.6
	1	3	1	18.4	55	0.0372	1.5
	2	1	2	50.6	51	0.0372	1.4
8	0	69	8	4.5	311	0.0205	15.1
	1	21	1	18.2	382	0.0205	18.6
	2	12	1	46.7	560	0.0205	27.3

Holding and Spawning

Spring-run chinook salmon and summer-run steelhead enter Canyon Creek during May, June, July and August (Table 22). During mid-August 1985, 10 summer-run steelhead and 29 spring-run chinook salmon were observed in Canyon Creek. Five chinook had adipose fin clips and one chinook had both an adipose fine clip and a green spaghetti tag (CFG tag, Willow Creek weir, Trinity River). No adult steelhead were marked or tagged. Estimated total lengths of adult chinook salmon ranged from 50 to 75 cm and adult steelhead from 40 to 50 cm. Adult salmonids were found in low velocity pools 3 m deep and high velocity bedrock chutes 0.5 m deep, 70% of the adult salmonids holding in Canyon Creek were in pools 1 to 1.5 m deep.

Table 22. Spring and summer-run adult salmonids holding in Canyon Creek, Trinity County, California.

Year	Steelhead			Chinook		
	Unmarked	Marked[a]	Total	Unmarked	Marked[a]	Total
1980[b]			6			29
1981[b]			3			-
1982[c]	4	-	4	3	-	3
1983[d]	3	-	3	6	21	27
1985[c]	10	-	10	24	5	29

[a] Adipose fin clip.

[b] Freese, J.L. NMFS, Auke Bay, Alaska, personal communication. Method: underwater observation.

[c] Present study. Method: underwater observation.

[d] California Department of Fish and Game, Anadromous Fisheries Branch, Arcata. Method: upstream migrant trap (July-August).

In 1983-1985, 35 steelhead redds, 21 chinook salmon redds and 1 coho salmon redd were located in Canyon Creek (Figure 21). Physical parameters of spawning areas and redds were measured where sites were accessible. Water depth at 21 steelhead redds in 1984 and 1985 averaged 29.6 cm SD 13.3 and water velocity averaged 61.5 cm/s SD 20.8 (Table 23). The average redd area was 2.17 m^2. Substrate at 11 steelhead spawning areas had an average geometric mean particle diameter of 23.5 mm SD 11.2 and an average fredle index value of 12.6 SD 10.1.

The spawning areas of fall-run and spring-run chinook salmon were measured separately. Water depth at 10 fall-run chinook redds averaged 32.9 cm SD 9.4 in 1983-1985 and water velocity at 9 redds averaged 58.1 cm/s SD 9.4 (Table 24). The average area of 11 redds was 5.42 m^2 SD 3.37. Substrate at the spawning areas of 5 fall-run chinook redds had an average geometric mean particle diameter of 24.6 mm SD 8.2 and an average fredle index value of 13.0 SD 6.5. Water depth at 9 spring-run chinook redds in 1985 averaged 19.8 cm SD 5.4 and water velocity averaged 40.9 cm/s SD 13.4. The average spring-run chinook redd was 4.32 m^2 SD 1.91 (Table 25)

The time of spawning and distribution of salmonid redds in Canyon Creek were consistent during the three spawning seasons. Steelhead redds were distributed in the lower 18 km of Canyon Creek and in two tributaries, Clear and Ripstein gulches (Figure 21). Superimposition of redds was observed twice at the most heavily utilized steelhead spawning area 3 km above the mouth of Canyon Creek. Adult steelhead were observed courting and actively constructing redds from late February through May.

All fall-run chinook salmon spawning occurred in the lower 2 km of Canyon Creek with the exception of one redd 6 km above the stream's mouth (Figure 21). At the upstream site, a single fall-run chinook salmon redd was constructed in both the 1984 and 1985 spawning seasons. Fall-run chinook salmon were observed actively constructing redds from late October through November. Spring-run chinook salmon spawned 8 to 12 km above the mouth of Canyon Creek (Figure 21). Spring-run chinook salmon redds were

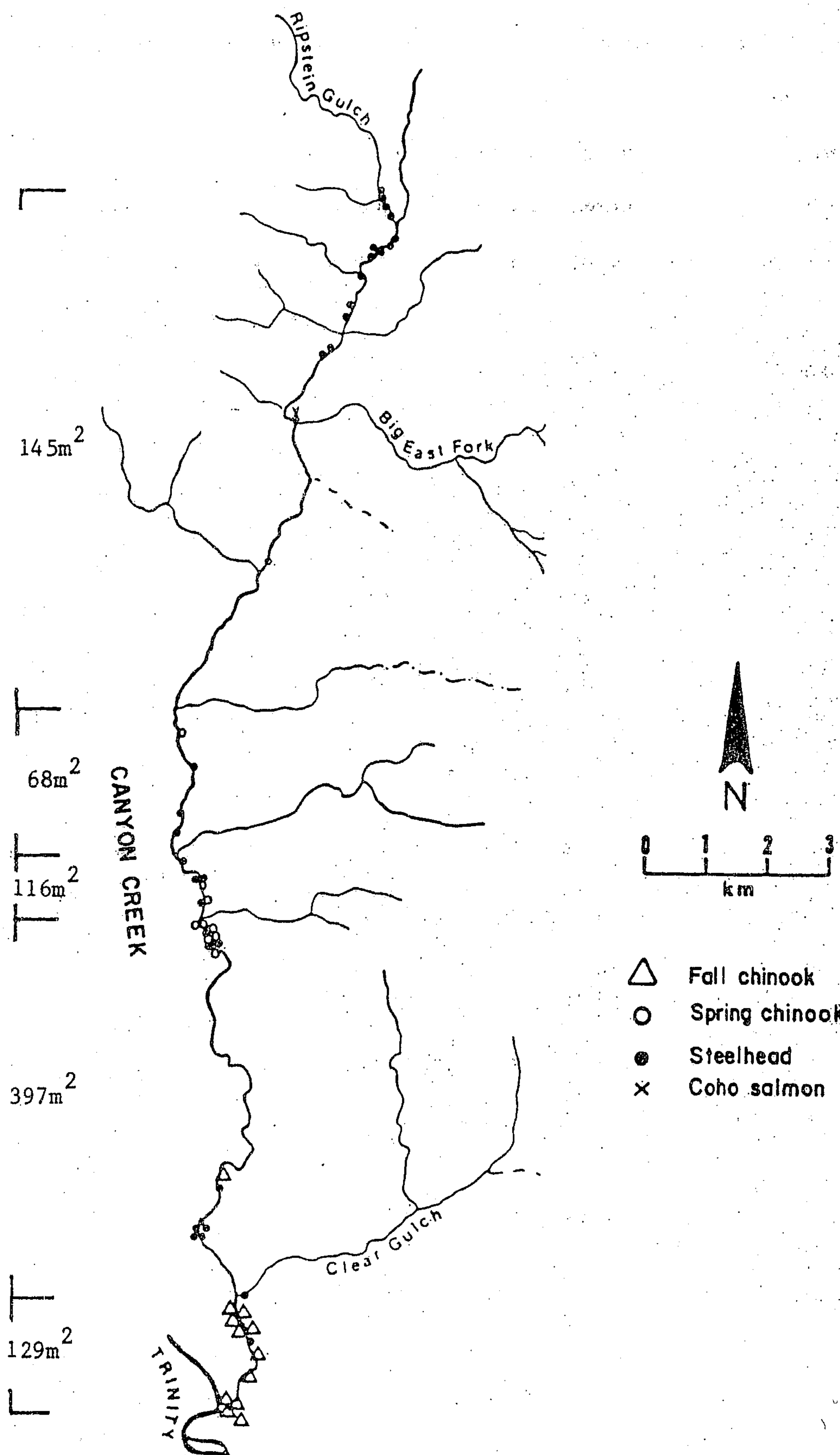

Figure 21. Salmon and steelhead redd location 1983-1985, in relation to available spawning gravel, Canyon Creek, Trinity County, California.

constructed in mid-October prior to increased streamflows, but coincident with a drop in water temperature.

The estimated total available spawning gravel in the lower 18 km of Canyon Creek was 855 m^2 (Figure 21). Fall-run chinook that utilized the lower 2 km of stream had 129 m^2 of available spawning gravel. Spring-run chinook utilized an area that had 342 m^2 of available spawning gravel. The entire 855 m^2 of suitable gravel were available to spawning steelhead.

Table 23. Physical parameters at steelhead redds in Canyon Creek, Trinity County, California.

Date	Redd No.	Redd area (m^2)	Substrate: Geometric mean diameter (mm)	Substrate: Fredle index	Water: Depth (cm)	Water: Velocity (cm/s)
Feb 26, 1984	1	2.81	20.2	8.8	15.2	44.5
Mar 4, 1984	2	2.86	47.1	37.3	21.3	59.8
"	3	2.61	29.2	17.9	30.5	84.8
"	4	1.47	30.5	13.3	24.4	72.6
Mar 31, 1984	5	3.51	13.1	2.1	21.3	61.8
Apr 4, 1984	6	6.83	8.5	2.3	6.1	12.3
"	7	2.60	22.2	9.7	27.4	69.5
"	8	1.12	--		18.3	71.9
"	9	1.82	14.0	4.3	30.5	40.3
"	10	1.21	12.3	4.8	30.5	74.2
Apr 14, 1984	11	1.51	--	--	18.3	45.5
"	12	1.78	25.5	15.7	24.4	79.9
Feb 5, 1985	13	1.47	36.4	22.4	19.8	19.0
Mar 19, 1985	14	3.12	--	--	27.4	95.6
May 16, 1985	15	0.82	--	--	64.0	83.1
May 29, 1985	16	1.39	--	--	39.6	53.7
"	17	0.42	--	--	27.4	46.6
"	18	1.12	--	--	42.7	58.9
"	19	1.86	--	--	33.5	83.9
"	20	1.95	--	--	57.9	63.2
"	21	3.35	--	--	41.1	70.3
Mean		2.17	23.5	12.6	29.6	61.5

Table 24. Physical parameters at fall-run chinook salmon redds in Canyon Creek, Trinity County, California.

Date	Redd No.	Redd area (m^2)	Substrate: Geometric mean diameter (mm)	Substrate: Fredle index	Water: Depth (cm)	Water: Velocity (cm/s)
Nov. 11, 1983	1	4.16	23.3	10.1	18.3	68.7
Oct. 24, 1984	2	9.48	--	--	18.3	51.8
"	3	2.16	20.6	8.9	--	--
"	4	10.04	34.7	21.3	27.4	48.4
Nov. 3, 1984	5	1.67	32.2	19.8	33.5	--
Oct. 31, 1984	6	8.46	12.1	4.7	39.6	73.7
Nov. 17, 1984	7	2.97	--	--	45.7	70.8
Oct. 27, 1985	8	2.12	--	--	36.6	54.3
"	9	1.67	--	--	27.4	53.4
"	10	9.62	--	--	36.6	54.0
"	11	7.25	--	--	45.7	48.2
Mean		5.24	24.6	6.5	32.9	58.1

Table 25. Physical parameters at spring-run chinook salmon redds in Canyon Creek, Trinity County, California.

Date	Redd	Redd area (m^2)	Water: Depth (cm)	Water: Velocity (cm/s)
Oct. 20, 1985	1	5.02	21.3	35.1
"	2	2.93	12.2	61.2
"	3	2.12	9.1	61.8
"	4	0.93	24.4	41.3
"	5	5.86	21.3	49.2
"	6	7.43	24.3	27.9
"	7	5.58	18.3	36.9
"	8	4.88	21.3	34.8
"	9	4.09	25.9	19.9
Mean		4.32	19.8	40.9

Emergence

High winter and spring flows greatly limited the ability to observe timing and duration of salmonid fry emergence. Due to steep and rough stream edges and limited side channels on Canyon Creek, the majority of salmonid fry probably remain under rocks and crevices during high streamflow. Chinook salmon fry were first observed in late February and reared in the slow velocity areas along the lower 2 km of the stream until mid-May. No young chinook salmon were observed or captured in Canyon Creek after May. Coho salmon young were observed to just below Big East Fork in Canyon Creek, juveniles held in various pools for over 1 year before entering the Trinity River. Steelhead fry were first observed in early May in the lower portions of the stream and in mid-June in the upper reaches of the study area. Steelhead sac fry continued to emerge through July in the vicinity of Ripstein Gulch.

Holding, Spawning and Dredging

Anadromous salmonids held and spawned in Canyon Creek in close proximity to suction dredge activity. During the 1984-1985 spawning season, fall-run chinook salmon, coho salmon and steelhead spawned in areas actively dredged during the 1984 dredge season (Figure 22). In August 1985, spring-run chinook salmon and summer-run steelhead were holding near areas where suction dredges were being operated (Figure 23). During the 1985 spawning season, fall and spring-run chinook salmon spawned in areas actively dredged during the 1985 dredge season (Figure 24).

Invertebrates

Fifty six BAS samplers were recovered out of the 84 deployed due to high water. Ninety-four taxa were identified from BAS samples (Table 26). The number of taxa found in a sampler ranged from 8 to 35 (generally 15-25). Common taxa that occurred only in BEF included: Cinygma sp., Epeorus (Ironopsis) sp., and Visoka cataractae. Analysis of

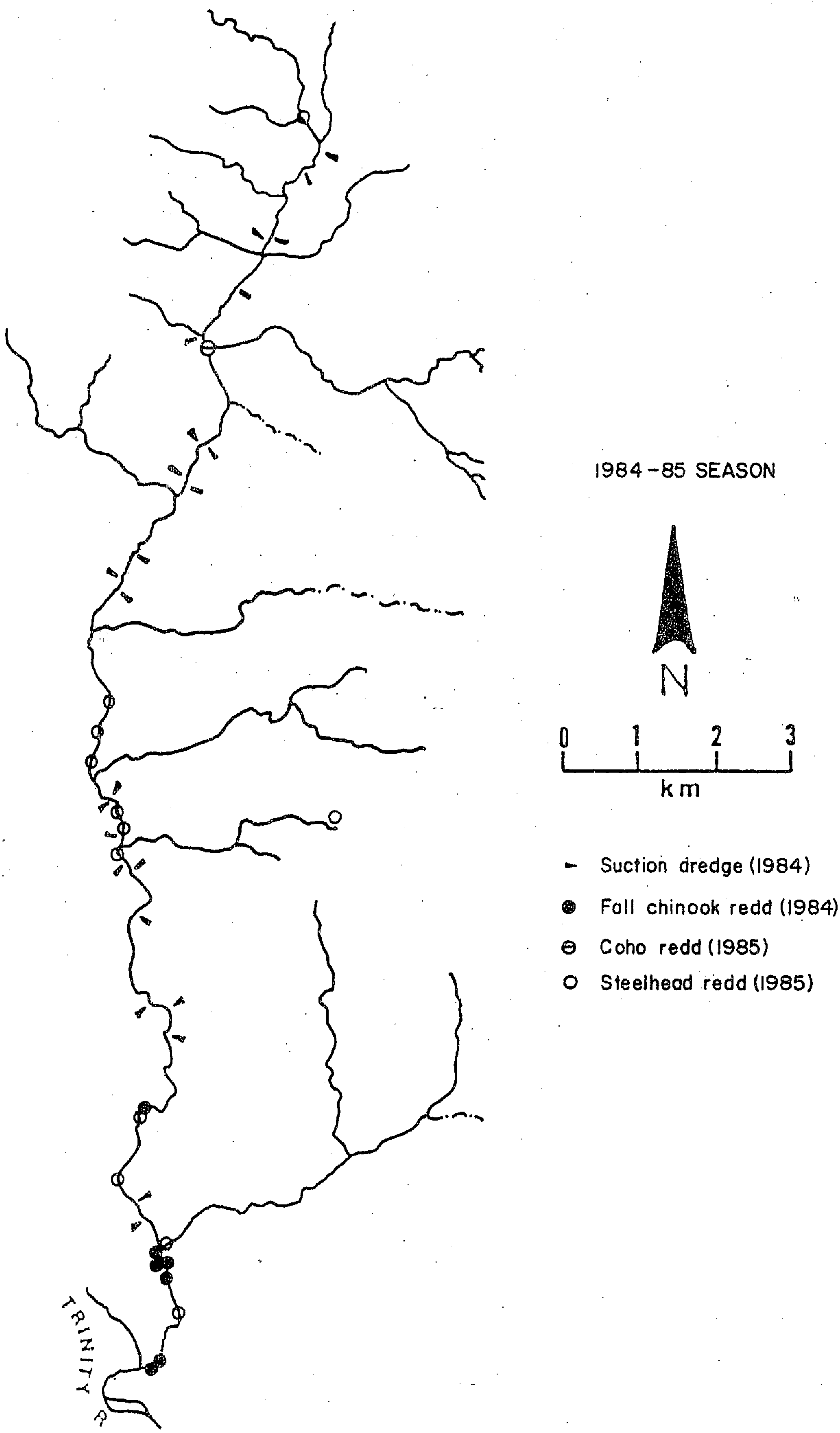

Figure 22. Salmon and steelhead redd location in relation to suction dredge mining activity, Canyon Creek, Trinity County, California.

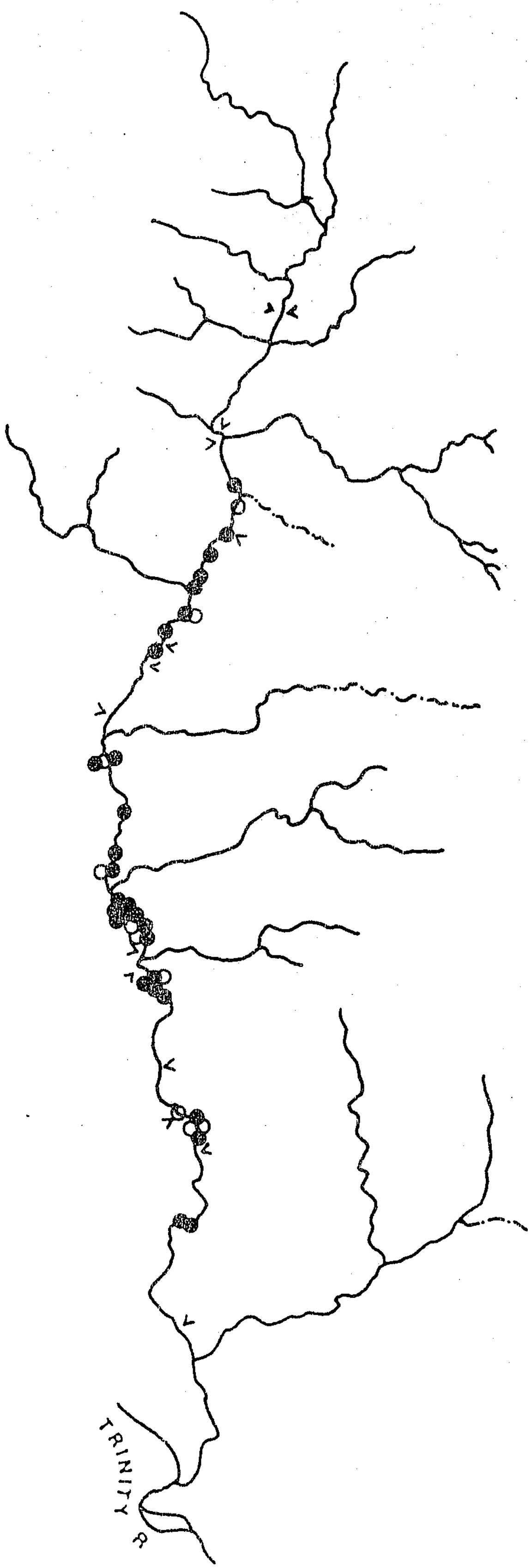

Figure 23. Distribution of spring-run chinook salmon and summer-run steelhead in August, 1985, in relation to suction dredge mining activity, Canyon Creek, Trinity County, California.

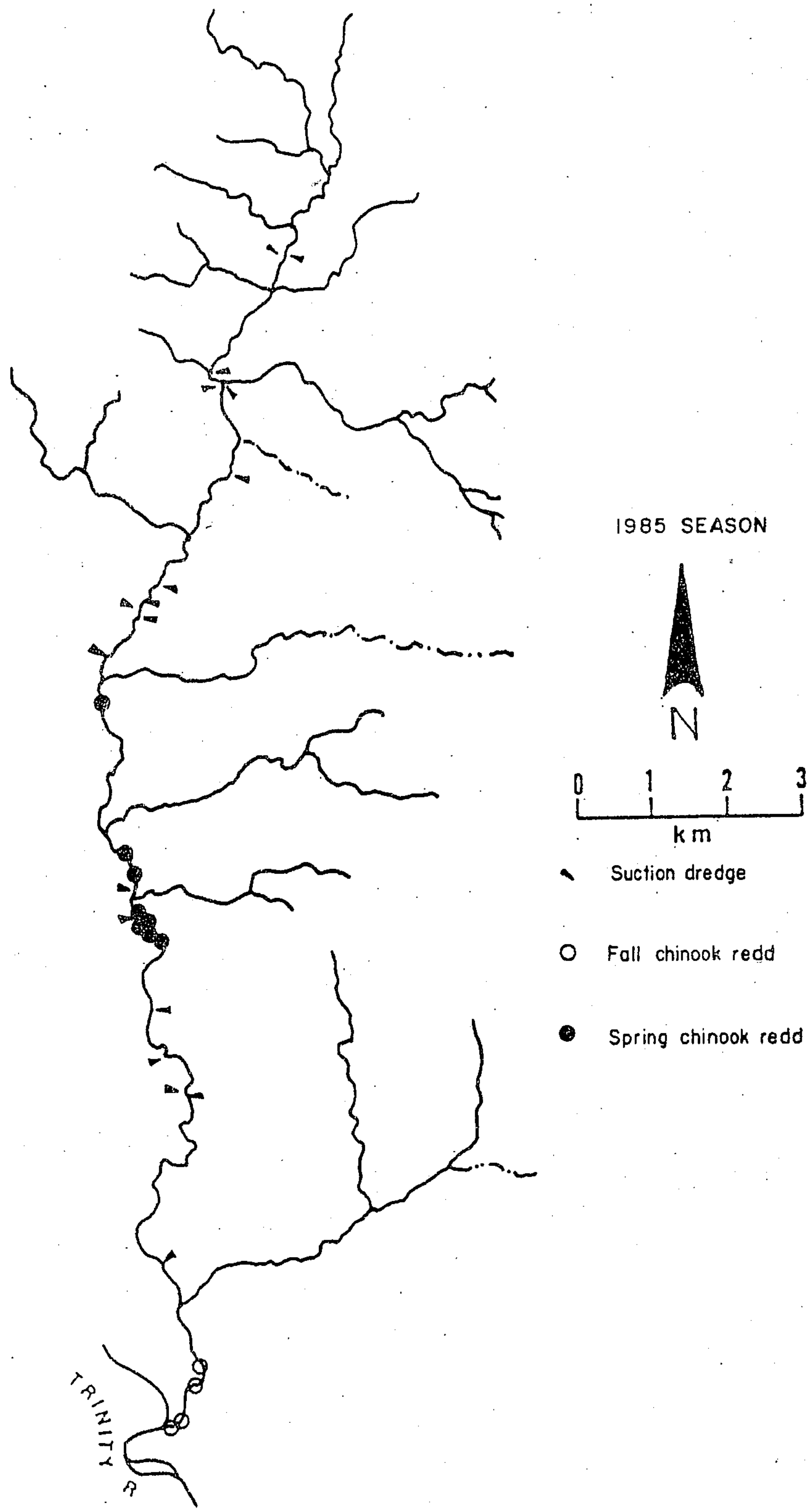

Figure 24. Chinook salmon redd location in relation to suction dredge mining activity, Canyon Creek, Trinity County, California.

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983.

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a] Drift	Kick	BAS Site[b] 1	2	3	4
ANNELIDA							
OLIGOCHAETA							
Lumbriculida	Gatherer	x	x	x	x	x	x
ARTHROPODA							
ARACHNIDA							
Acari	Predator			x			x
CRUSTACEA							
Copepoda	No group[c]			x			
INSECTA							
Coleoptera							
Carabidae	Predator	x	x				
Elmidae							
Ampumixis dispar	Gatherer				x	x	x
Cleptelmis sp.	Gatherer		x				x
Lara sp.	Shredder				x	x	
Narpus sp.	Gatherer		x	x	x		x
Ordobrevia nubifera	Gatherer	x	x		x		x
Rhizelmis nigra	Gatherer		x	x	x		
Stenelmis sp.	Scraper	x	x				
Zaitzevia parvula	Gatherer		x				x
Collembola							
Isotomidae 1	Gatherer			x	x	x	
Isotomidae 2	Gatherer						x

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983. (continued)

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a]					
				BAS Site[b]			
		Drift	Kick	1	2	3	4
Diptera							
Ceratopogonidae							
Ceratopogoninae	Predator		x	x	x		
Dashyheleinae	Gatherer				x		
Chironomidae							
Chironominae							
Tanytarsus sp.	Filterer		x	x	x	x	x
Chironomini (Tribe)	Gatherer	x	x	x	x	x	x
Orthocladinae							
Corynoneura sp.	Gatherer	x	x	x	x	x	x
Eukiefferiella sp.	Gatherer	x	x	x	x	x	x
Krenosmittia sp.	Gatherer				x		x
Tanypodinae							
Paramerina sp.	Predator		x	x	x	x	x
Podominae							
Boreochlus sp.	Gatherer			x	x		
Dolichopodidae	Predator				x		
Empididae							
Chelifera sp.	Predator						x
Clinocera sp.	Predator				x		
Oreogeten sp.	Predator		x	x	x		x
Pelecorhynchidae							
Glutops sp.	Predator		x				
Psychodidae	Gatherer	x	x	x	x		x

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983. (continued)

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a] Drift	Kick	BAS Site[b] 1	2	3	4
Simuliidae							
Simulium sp.	Filterer	x	x	x	x		x
Tabanidae (genera unseperable)	Predator		x				
Tipulidae							
Dicranota sp.	Predator		x	x	x		x
Hexatoma sp.	Predator		x				
Pedicia sp.	Predator						x
Rhabdomastix sp.	Predator				x		
Ephemeroptera							
Baetidae							
Baetis sp.	Gatherer	x	x	x	x	x	x
Ephemerellidae							
Caudatella hystrix	Gatherer	x	x	x	x		x
Drunella doddsi	Predator		x	x	x	x	x
Drunella spinifera	Predator		x	x	x	x	
Serratella levis	Gatherer	x	x	x	x	x	x
Serratella micheneri	Gatherer			x	x	x	
Serratella teresa	Gatherer			x		x	
Heptageniidae							
Cinqama sp.	Scraper			x	x		
Cinyqmula sp.	Scraper	x	x	x	x	x	x
Epeorus (Iron) sp.	Gatherer		x	x	x	x	x
Epeorus (Ironopsis) sp.	Gatherer	x	x	x	x		

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983. (continued)

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a] Drift	Sampler[a] Kick	BAS Site[b] 1	BAS Site[b] 2	BAS Site[b] 3	BAS Site[b] 4
Ironodes sp.	Scraper	x	x	x		x	
Rhithrogena sp.	Gatherer	x	x	x	x	x	x
Leptophlebiidae							
Paraleptophlebia so.	Gatherer	x	x	x	x		x
Siphlonuridae							
Ameletus sp.	Gatherer		x	x	x	x	x
Hemiptera							
Veliidae							
Microvelia sp.	Predator					x	
Lepidoptera							
Pyralidae							
Crambus sp.	Shredder	x					x
Cosmopteryqidae							
Pyroderces sp.	Shredder						x
Meqaloptera							
Corydalidae							
Orohermes crepusculus	Predator		x				
Odonata							
Gophidae							
Ophioqomphus sp.	Predator				x		
Plecoptera							
Capniidae							
Mesocapnia sp.	Shredder	x	x	x	x	x	x
Chloroperlidae							

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983. (continued)

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a]					
		Drift	Kick	BAS Site[b] 1	2	3	4
Sweltsa sp.	Predator		x		x		
Nemouridae							
Malenka sp.	Shredder	x	x	x	x	x	x
Visoka cataractae	Shredder	x	x	x	x		
Zapada cinctipes	Shredder		x	x	x	x	x
Zapada columbiana	Shredder	x	x	x	x	x	x
Peltoperlidae							
Sierraperla cora	Shredder		x	x			
Soliperla sp.	Shredder				x		
Yoraperla brevis	Shredder			x	x	x	x
Perlidae							
Calineuria californica	Predator	x	x	x	x	x	x
Doroneuria baumanni	Predator		x	x	x		x
Perlodidae							
Diura sp.	Scraper			x	x		
Megarcys sp.	Predator		x				
Perlinodes aurea	Predator		x				
Skwala sp.	Predator		x	x	x		
undescribed gen.	Unknown		x				
Pteronarcidae							
Pteronarcys princeps	Shredder		x	x			
Trichoptera							
Brachycentridae							
Oligoplectrum echo	Filterer				x		x

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983. (continued)

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a]					
		Drift	Kick	BAS Site[b] 1	2	3	4
Micrasema sp.	Shredder			x			
Calamoceratidae							
Heteroplectron californicum	Shredder			x			
Glossosomatidae							
Agapetus sp.	Scraper						x
Glossosoma sp.	Scraper		x	x	x		x
Hydropsychidae							
Arctopsyche grandis	Filterer		x	x	x		
Hydropsyche sp.	Filterer	x	x	x	x	x	x
Parapsyche sp.	Filterer			x	x		
Lepidostomatidae							
Lepidostoma sp.	Shredder	x		x	x		x
Limnephilidae							
Apatania sp.	Scraper				x		
Ecclisomyia sp.	Gatherer		x	x	x	x	x
Neophylax sp.	Scraper		x			x	x
Philopotamidae							
Dolophilodes sp.	Filterer		x		x		
Polycentropodidae							
Polycentropus sp.	Predator		x	x	x		
Psychomyiidae							
Tinodes sp.	Scraper		x				

Table 26. Aquatic Invertebrates Captured with Different Gear in Relation to Suction Dredge Mining in Canyon Creek, California, September to November, 1983. (continued)

PHYLUM CLASS Subclass Order Family Subfamily Genus species	Functional group	Sampler[a] Drift	Kick	BAS Site[b] 1	2	3	4
Rhyacophilidae							
Rhyacophila sp. 1	Predator	x	x	x	x	x	x
Rhyacophila sp. 2	Predator	x	x	x	x	x	x
Rhyacophila sp. 3	Predator		x	x	x		x
Rhyacophila sp. 4	Predator		x	x	x		x
Rhyacophila sp. 5	Predator			x	x		
Rhyacophila sp. 6	Predator				x		
NEMATODA	no group[c]			x	x		
NEMATOMORPHA							
GORDIOIDEA							
Gordiidae							
Gordius sp.	no group[c]			x	x	x	

[a]Drift and Kick samples taken at each BAS sampler site.

[b]BAS sampling sites are designated as follows: 1, Big East Fork above dredge; 2, Big East Fork below dredge; 3, Canyon Creek above BEF; 4, Canyon Creek below BEF.

[c]No functional grouping assigned or analyzed.

Perlodidae was to family. Functional feeding groups assigned to the taxa are reported in Table 26.

BEF

The analysis of BEF samplers revealed different invertebrate colonization trends with time above and below mining operation. Mean number of invertebrates per sampler was not significantly different for site or time (Table 27). An initial population increase that declined over time was apparent (Figure 25). Mean Shannon-Weaver Diversity and Equitability Indices per BAS sampler increased significantly ($\underline{P} \leq 0.001$, $\underline{P} \leq 0.005$, respectively) with time, but were not significantly different between sites (Table 27, Figure 26).

Annelida colonization in BEF had a significant site x time interaction (Table 27, Figure 27). The mean number of Annelids above dredge was not significantly different with time, but mean number below dredge was significantly higher at 6 weeks than 2 weeks (Table 28).

Mean number of Diptera per BAS sampler significantly ($\underline{P} \leq 0.007$) decreased with time and was significantly higher ($\underline{P} \leq 0.045$) below dredge than above (Table 27, Figure 27). Diptera taxa colonization generally followed the ordinal response (Table 29). Mean number of Chironomidae and Eukiefferiella sp. decreased significantly ($\underline{P} \leq 0.006$, $\underline{P} \leq 0.026$, respectively) with time, and Chironomidae indicated a trend ($\underline{P} \leq 0.065$) of higher numbers below dredge (Tables 29 and 30). A significant ($\underline{P} \leq 0.006$) site x time interaction indicated differential colonization by Corynoneura sp. at both above and below dredge (Table 28).

The mean number of Ephemeroptera per BAS sampler was not different by site or time (Table 27, Figure 27). Colonization of samplers varied widely among Ephemeropteran taxa (Table 29). Interaction effects ($\underline{P} \leq 0.070$, $\underline{P} \leq 0.018$) were indicated for mean number of Ephemerellidae and Rhithrogena sp. (Table 29) but ANOVA did not show significant responses for these groups (Table 28). Mean number of Cinygmula sp. per BAS sampler was significantly ($\underline{P} \leq 0.024$) higher above dredge than below dredge (Tables 29 and 31).

Mean number Epeorus sp. per sampler significantly ($P \leq 0.018$) increased with time. Other Ephemeropteran taxa means tested were not significantly different for site and time.

The mean number of Plecoptera per BAS sampler was significantly ($P \leq 0.023$) different with time, but not for site (Table 27, Figure 28). Plecoptera colonization in samplers varied widely by taxa (Table 29). Mean number Visoka sp. was significantly higher ($P \leq 0.002$) above dredge (Table 32). Zapada sp. decreased significantly ($P \leq 0.037$) with time and indicated a trend ($P \leq 0.059$) of higher mean number above dredge. Mean number Calineuria californica was significantly ($P \leq 0.003$) higher below dredge. Mean number of Perlodidae significantly ($P \leq 0.001$) decreased with time, and were higher above dredge ($P \leq 0.084$) (Table 32). An interaction effect for mean number Perlodidae was not significant (Table 28).

Table 27. Analysis of variance of BAS samplers for Big East Fork Creek.

	Level of Significance[a]		
Variable	Site	Time	Site x Time
Number	NS	NS	NS
Shannon-Weaver	NS	0.001	NS
Equitability	NS	0.005	NS
Annelida	0.001	0.006	0.066
Diptera	0.045	0.007	NS
Ephemeroptera	NS	NS	NS
Plecoptera	NS	0.023	NS
Trichoptera	NS	NS	NS
% Predators	NS	0.070	NS
% Shredders	0.001	NS	NS
% Grazers	0.044	0.028	NS
% Gatherers	0.004	NS	NS
% Filterers	0.001	NS	0.030

[a]Significance levels >0.07 are indicated by NS.

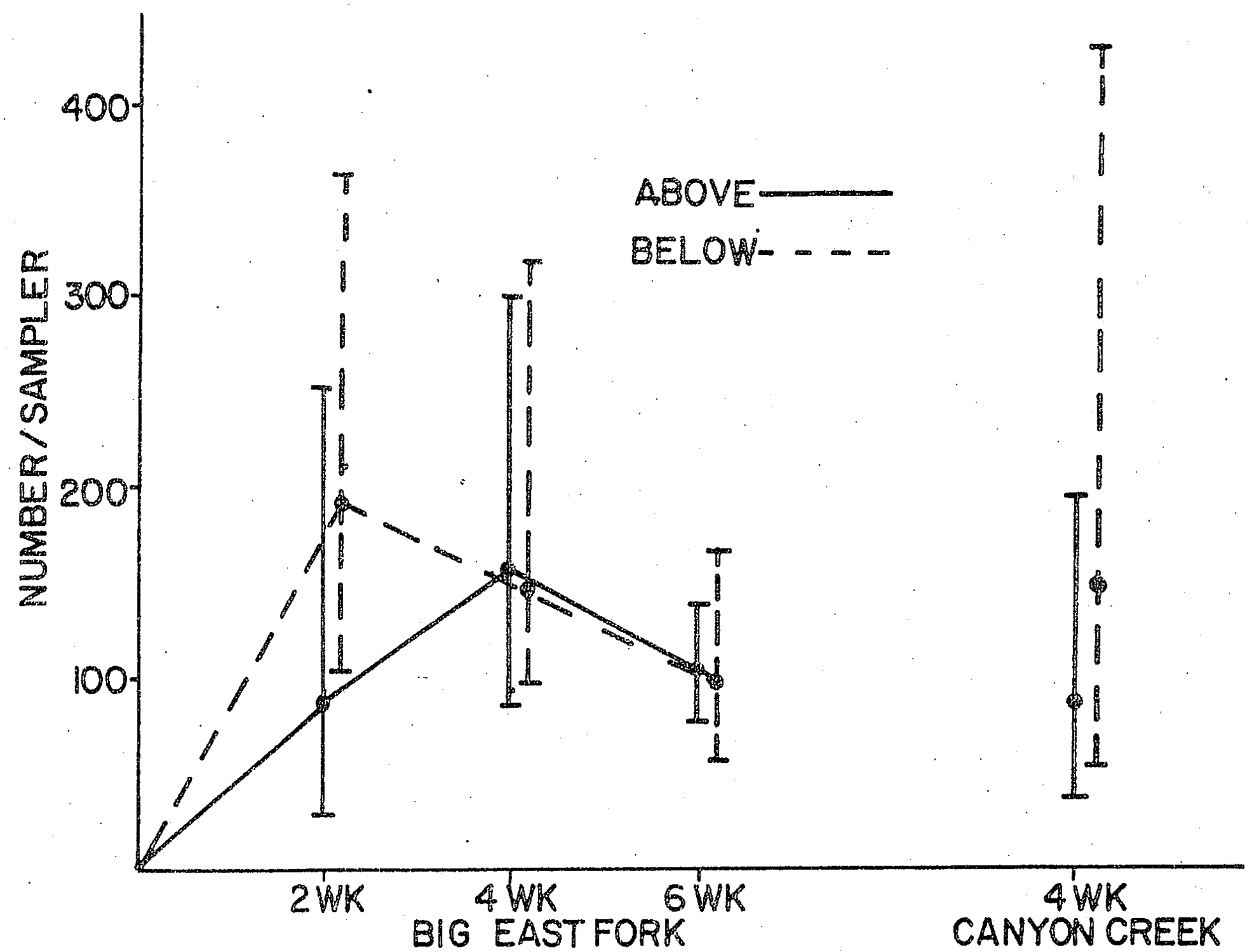

Figure 25. Geometric mean number and 95% confidence limits for invertebrates per sampler above and below dredge. Mean of 7 samplers.

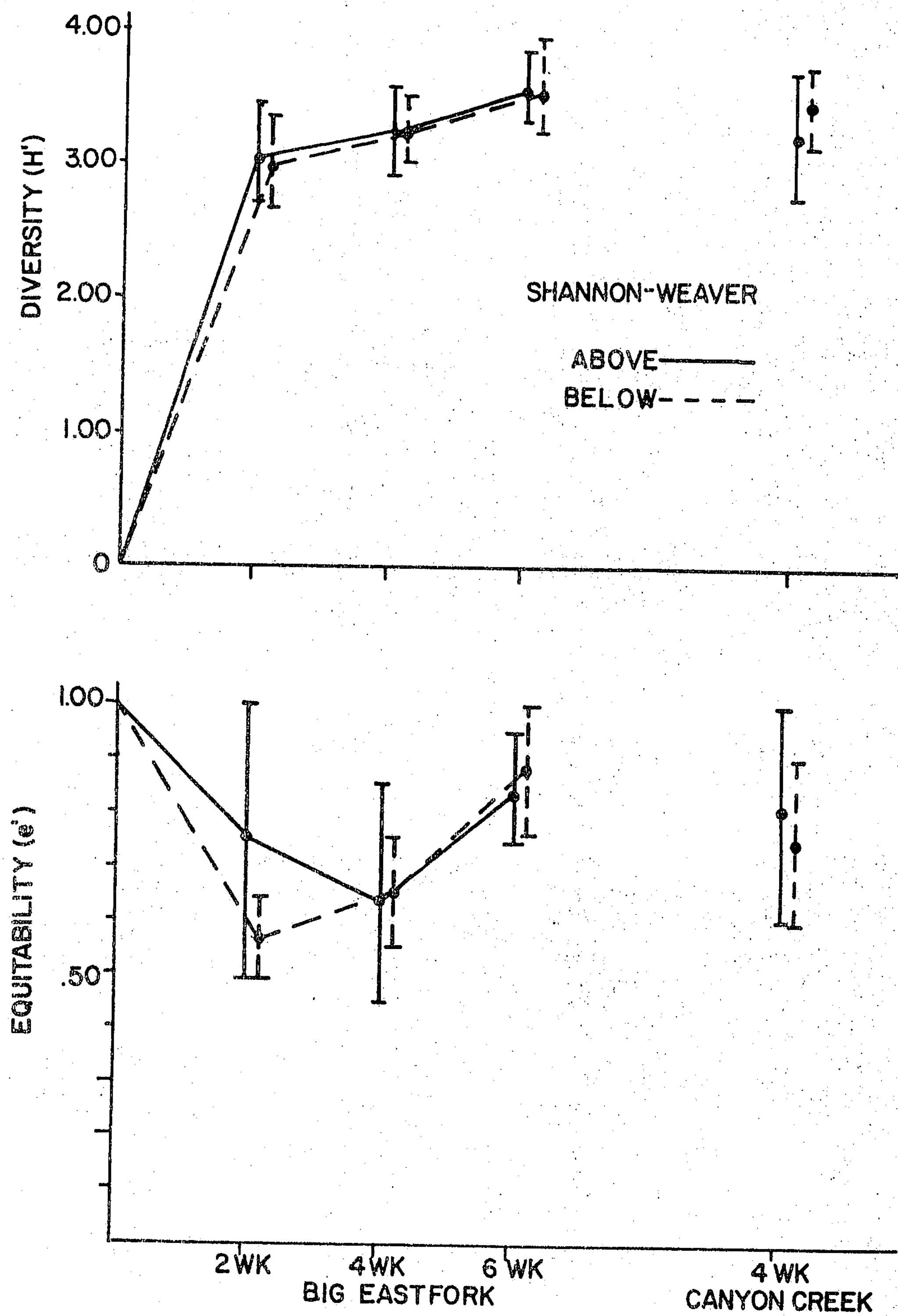

Figure 26. Geometric mean and 95% confidence limits for Shannon-Weaver Diversity Index and Equitability Index per sampler above and below dredge. Mean of 7 samplers.

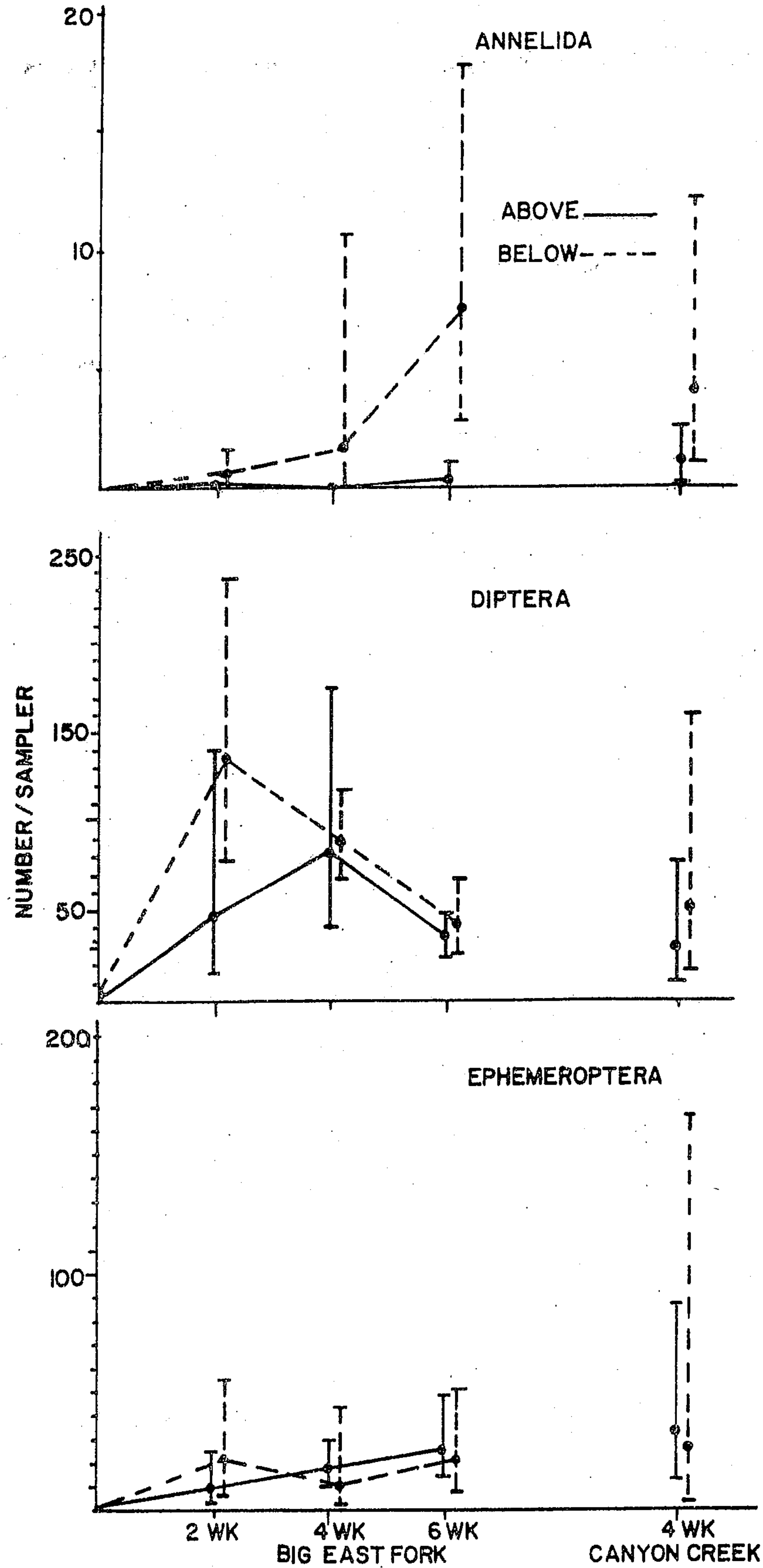

Figure 27. Geometric mean number and 95% confidence limits for Annelids, Diptera and Ephemeroptera per sampler above and below dredge. Mean of 7 samplers.

Table 28. Interaction tests for sample site by time for Big East Fork Creek.

Variable	Site[a]	One-way[b] Anova	Tukey[c]	Scheffe[c]
Annelida	Above	NS	NS	NS
	Below	0.024	6wk > 2wk	6wk > 2wk
Corynoneura sp.	Above	0.002	4wk>2, 6wk	4>6, 4>2wk
	Below	0.031	2wk > 6wk	2wk > 6wk
Ephemerellidae	Above	NS	NS	NS
	Below	NS	NS	NS
Rhithrogena sp.	Above	NS	NS	NS
	Below	NS	NS	NS
Perlodidae	Above	NS	NS	NS
	Below	NS	NS	NS
% Filterers	Above	NS	NS	NS
	Below	0.040	2wk > 6wk	2wk > 6wk

[a]Above dredge, site 1; below dredge, site 2.

[b]Significance level >0.05 are indicated by NS.

[c]Tukey and Scheffe nonorthogonae contrasts.

The mean number of Trichoptera per BAS sampler was not significantly different by site or time (Table 27, Figure 28). Colonization of samplers by Trichopteran taxa showed no significant responses to dredging (Table 29). Mean number Hydropsychidae per BAS sampler decreased ($P \leq 0.056$) with time (Table 33). Significant ($P \leq 0.001$) differences in mean number of *Ecclisomyia* sp. per sampler occurred with time, peaking at week 4.

Functional feeding group percent composition summarized trophic responses to dredging in BEF. An increasing trend for predators with time was suggested ($P \leq 0.070$) (Table 27, Figure 29). Mean percent shredders was significantly ($P \leq 0.001$) higher above dredge. The grazer component significantly ($P \leq 0.028$) increased with time, and was significantly ($P \leq 0.044$) greater above dredge (Figure 30). The gatherers component was significantly higher ($P \leq 0.004$) below dredge. A significant ($P \leq 0.030$) site x time interaction for mean percent filterers per sampler suggested differential colonization (Figure 30). Mean percent filterers per sampler above dredge was not significantly different with time, however, filterers decreased ($P \leq 0.040$) with time below dredge (Table 28, Figure 30).

Table 29. Analysis of variance by taxa for Big East Fork Creek.

	Level of Significance[a]		
Variable	Site	Time	Site x Time
Elmidae	NS	NS	NS
Chironomidae	0.065	0.006	NS
Corynoneura sp.	0.009	0.003	0.006
Eukiefferiella sp.	NS	0.026	NS
Baetis sp.	NS	NS	NS
Ephemerellidae	NS	NS	0.070
Drunella sp.	NS	NS	NS
Serratella sp.	NS	NS	NS
Heptageniidae	NS	NS	NS
Cinygmula sp.	0.024	NS	NS
Epeorus sp.	NS	NS	NS
Rhithrogena sp.	0.094	NS	0.018
Paraleptophlebia sp.	NS	NS	NS
Ameletus sp.	NS	NS	NS
Mesocapnia sp.	NS	NS	NS
Nemouridae	NS	NS	NS
Visoka cataractae	0.002	NS	NS
Zapada sp.	0.059	0.037	NS
Calineuria californica	0.003	NS	NS
Perlodidae	0.084	0.001	0.079
Hydropsychidae	NS	0.056	NS
Lepidostoma sp.	NS	NS	NS
Ecclisomyia sp.	NS	0.001	NS
Rhyacophila sp.	NS	NS	NS

[a]Significance levels ≥ 0.1 are indicated by NS.

Table 30. Mean number and standard error of the mean in parenthesis for diptera taxonomic groups with significantly different means in ANOVA tests. Mean of 7 samplers.

Site	Chironomidae	*Corynoneura* sp.	*Eukiefferiella* sp.
Big East Fork above dredge (1)			
Week two	46.53 (0.55)	8.75 (0.45)	21.39 (0.77)
Week four	84.11 (0.34)	29.06 (0.29)	39.46 (0.43)
Week six	34.81 (0.14)	4.09 (0.25)	18.23 (0.28)
Big East Fork below dredge (2)			
Week two	127.82 (0.23)	50.17 (0.30)	33.67 (0.26)
Week four	87.72 (0.12)	17.49 (0.50)	38.08 (0.17)
Week six	40.59 (0.21)	12.46 (0.40)	11.94 (0.27)
Canyon Creek above BEF (3)			
Week four	30.84 (0.46)	2.93 (0.46)	14.31 (0.47)
Canyon Creek below BEF (4)			
Week four	50.76 (0.61)	5.00 (0.55)	24.88 (0.63)

Table 31. Mean number and standard error of the mean in parenthesis for Ephemeropteran taxonomic groups with significant differences in ANOVA tests. Ephem, Ephemerellidae; Serr, Serratella species combined; Cinygm, Cinygmula sp.; Epeor, Epeorus species combined; Rhith, Rhithrogena sp.; Amel, Ameletus sp. Mean of 7 samplers.

	Taxonomic group					
Site	Ephem	Serr	Cinygm	Epeor	Rhith	Amel
Big East Fork above dredge (1)						
Week two	1.15 (0.38)	0.77 (0.33)	0.35 (0.15)	0.22 (0.14)	2.22 (0.47)	0.29 (0.19)
Week Four	2.71 (0.13)	1.03 (0.23)	0.17 (0.17)	0.22 (0.14)	3.24 (0.55)	0.69 (0.31)
Week six	3.73 (0.37)	3.02 (0.36)	1.67 (0.23)	3.82 (0.57)	2.72 (0.73)	1.64 (0.41)
Big East Fork below dredge (2)						
Week two	1.24 (0.29)	0.64 (0.22)	0.53 (0.26)	0.51 (0.22)	4.64 (0.67)	0.10 (0.10)
Week four	2.70 (0.49)	2.27 (0.53)	0.17 (0.17)	0.10 (0.10)	2.21 (0.64)	1.07 (0.26)
Week six	3.98 (0.54)	2.95 (0.61)	0.79 (0.32)	0.00 (0.00)	2.56 (0.77)	2.14 (0.41)
Canyon Creek above BEF (3)						
Week four	20.38 (0.32)	19.18 (0.32)	2.30 (0.46)	1.37 (0.41)	1.34 (0.43)	0.67 (0.21)
Canyon Creek below BEF (4)						
Week four	9.21 (0.69)	8.44 (0.73)	1.00 (0.41)	1.54 (0.57)	5.52 (0.89)	0.67 (0.28)

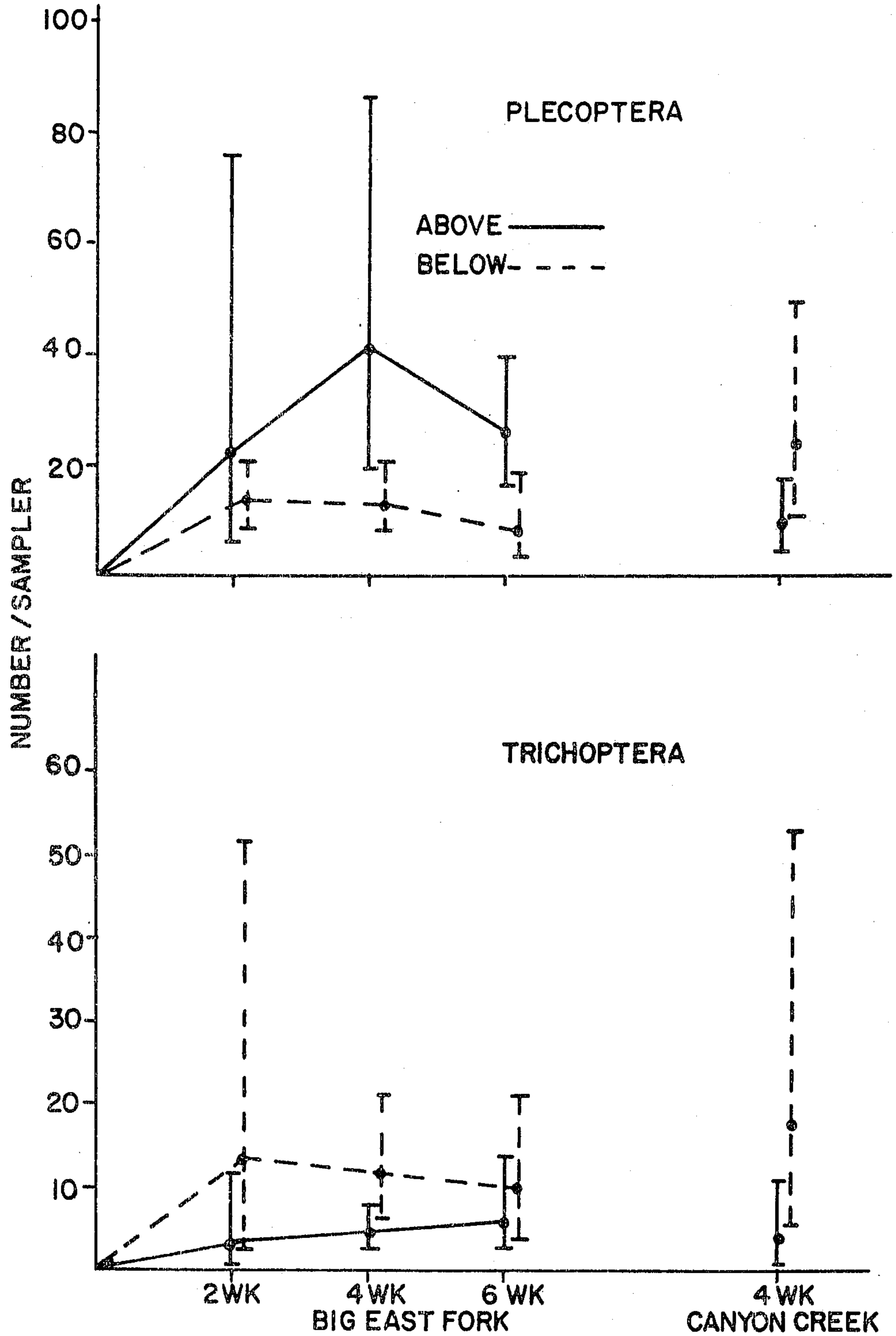

Figure 28. Geometric mean number and 95% confidence limits for Plecoptera and Tricoptera per sampler above and below dredge. Mean of 7 samplers.

Table 32. Mean number and standard error of the mean in parenthesis of Plecoptera taxonomic groups with significant differences in ANOVA tests. Nemour, Nemouridae; Visoka, Visoka cataractae; Zapada, Zapada species combined; Calineu, Calineuria californica, Perlodid, Perlodidae. Mean of 7 samplers.

	Taxonomic group				
Site	Nemour	Visoka	Zapada	Calineu	Perlodid
Big East Fork above dredge (1)					
Week two	12.09 (0.79)	0.22 (0.22)	9.35 (0.89)	0.37 (0.22)	0.93 (0.43)
Week four	19.70 (0.47)	1.86 (0.34)	13.66 (0.67)	4.32 (0.25)	1.54 (0.35)
Week six	5.76 (0.24)	2.19 (0.38)	2.61 (0.36)	3.56 (0.19)	0.51 (0.32)
Big East Fork below dredge (2)					
Week two	6.67 (0.43)	0.22 (0.14)	4.14 (0.55)	2.72 (0.32)	0.49 (0.35)
Week four	3.22 (0.34)	0.43 (0.19)	0.98 (0.52)	4.32 (0.16)	0.22 (0.14)
Week six	1.30 (0.39)	0.49 (0.23)	0.58 (0.35)	3.67 (0.29)	0.29 (0.29)
Canyon Creek above BEF (3)					
Week four	3.03 (0.36)	0.00 (0.00)	2.98 (0.35)	2.25 (0.29)	1.64 (0.24)
Canyon Creek below BEF (4)					
Week four	5.05 (0.61)	0.00 (0.00)	4.04 (0.65)	4.35 (0.35)	1.84 (0.29)

Table 33. Mean number and standard error of the mean in parenthesis for Trichoptera taxonomic groups with significantly different means in ANOVA tests. Mean of 7 samplers.

Site	Taxonomic group: Hydropsychidae	Taxonomic group: *Ecclisomyia* sp.
Big East Fork above dredge (1)		
Week two	0.94 (0.56)	0.10 (0.10)
Week four	0.49 (0.29)	0.22 (0.14)
Week six	0.17 (0.17)	0.10 (0.10)
Big East Fork below dredge (2)		
Week two	6.01 (1.06)	0.22 (0.22)
Week four	0.72 (0.55)	1.06 (0.48)
Week six	0.57 (0.42)	0.29 (0.19)
Canyon Creek above BEF (3)		
Week four	0.75 (0.33)	0.84 (0.39)
Canyon Creek below BEF (4)		
Week four	4.47 (1.02)	1.63 (0.39)

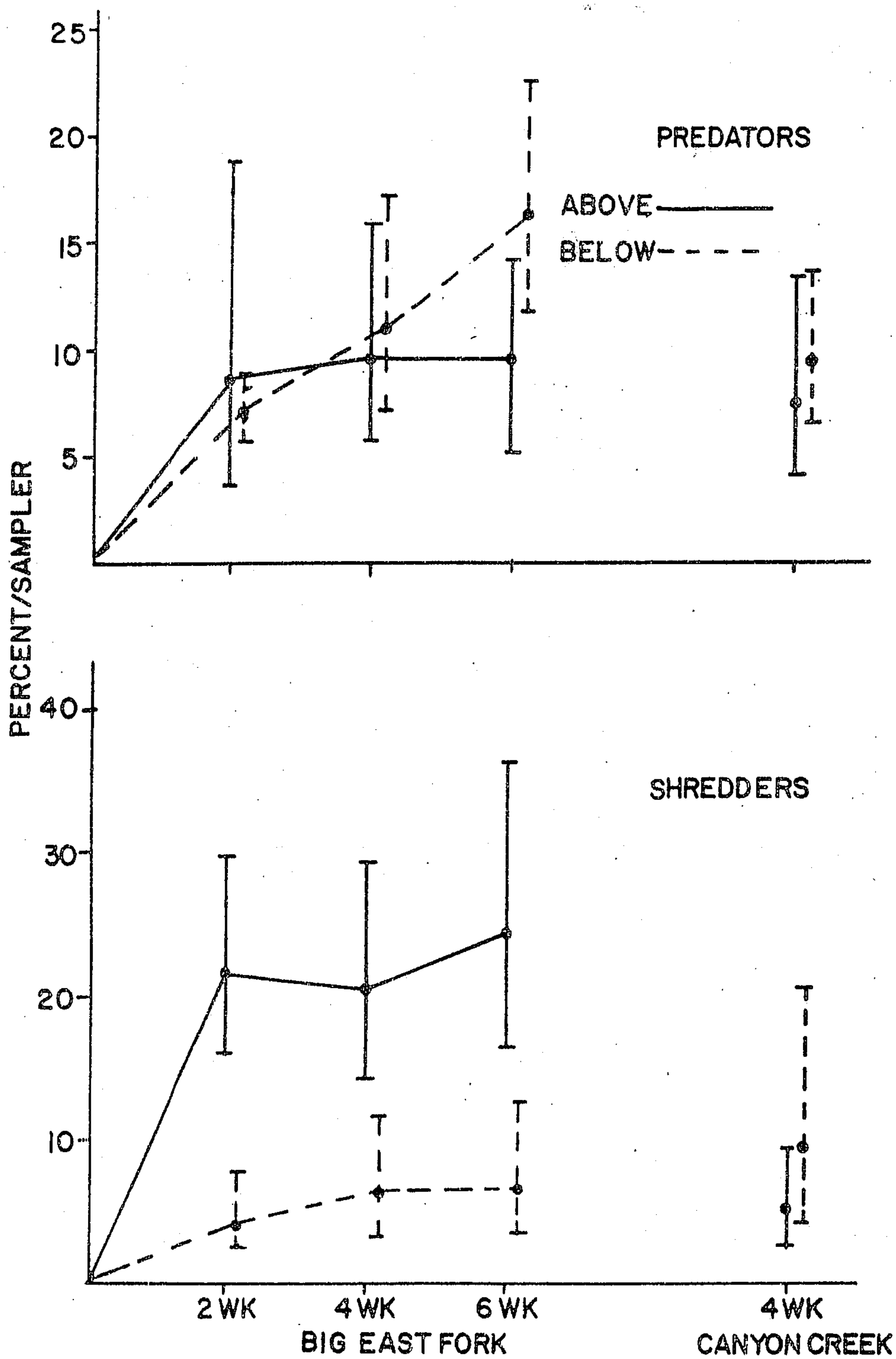

Figure 29. Geometric mean percentage and 95% confidence limits for predators and shredders per sampler above and below dredge. Mean of 7 samplers.

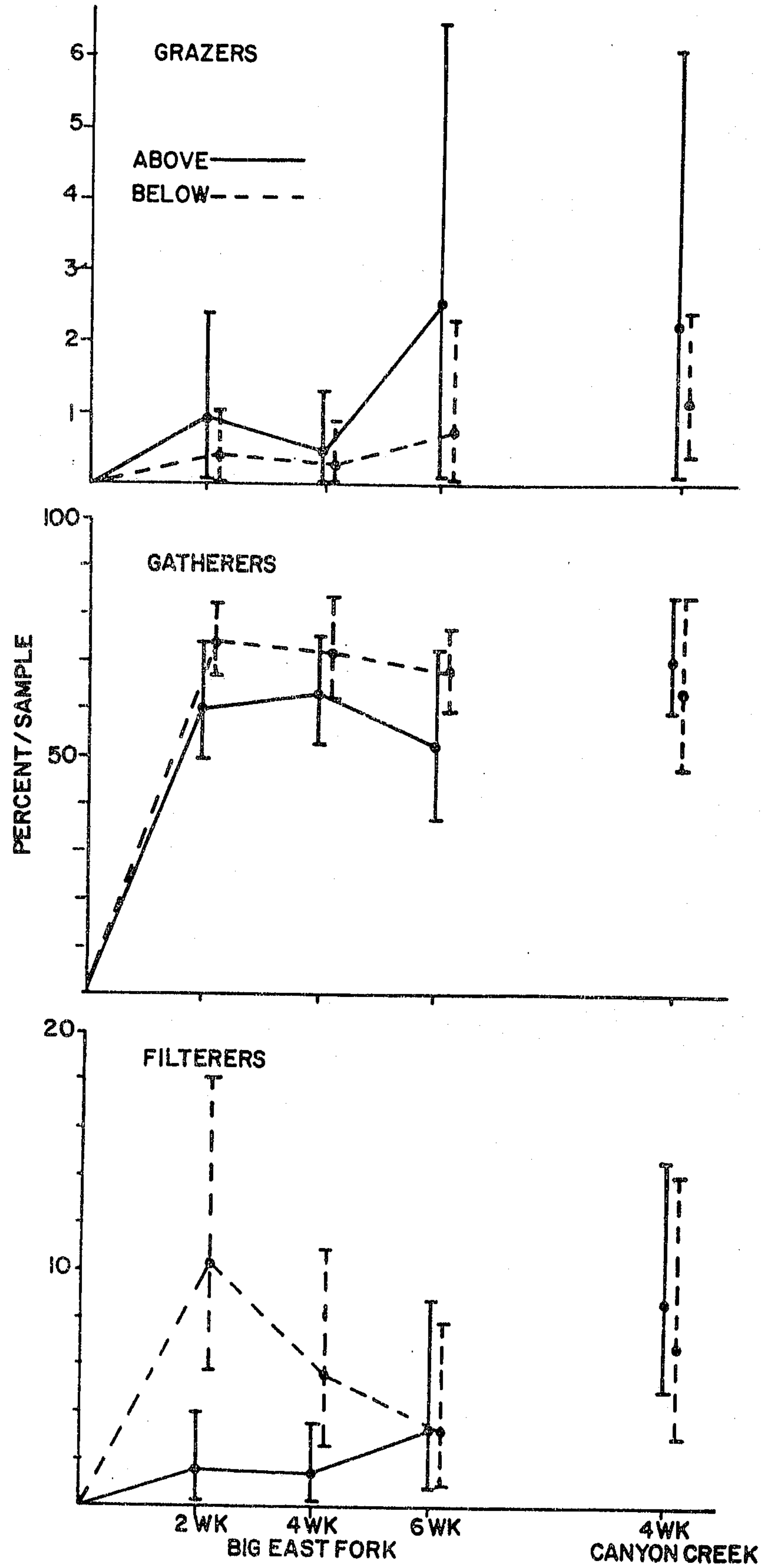

Figure 30. Geometric mean percentage and 95% confidence limits for grazers, gatherers and filterers per sampler above and below dredge. Mean of 7 samplers.

Canyon Creek -- BEF

The results of BAS sample data indicated that dredge impacts on benthic invertebrate populations in Canyon Creek were minimal during 1983. Mean total number of invertebrates per sampler was not significantly different between creeks (BEF versus Canyon Creek, sites on each creek pooled) or sites (above versus below dredge, both creeks pooled) for the four week colonization period (Table 34, Figure 25). No significant differences were found for Shannon-Weaver diversity and Equitability indices.

The mean number of Annelids per BAS sampler was not significantly different between creeks, but was significantly higher ($P \leq 0.011$) in below dredge samplers for both Canyon Creek and BEF (Table 34, Figure 27).

The mean number of Diptera per BAS sample was significantly greater ($P \leq 0.032$) for BEF samplers (Table 34, Figure 27). Diptera taxa followed the ordinal pattern of taxonomic resolution (Tables 30 and 35).

Table 34. Analysis of variance of BAS samplers from Big East Fork and Canyon Creek for the four week colonization period.

	Level of Significance[a]		
Variable	Creek	Site	Creek x Site
Number	NS	NS	NS
Shannon-Weaver	NS	NS	NS
Equitability	0.077	NS	NS
Annelida	0.075	0.012	NS
Diptera	0.032	NS	NS
Ephemeroptera	0.043	NS	NS
Plecoptera	NS	NS	NS
Trichoptera	0.053	NS	NS
% Predators	NS	NS	NS
% Shredders	0.058	NS	0.001
% Grazers	0.008	NS	NS
% Gatherers	NS	NS	NS
% Filterers	0.004	NS	0.021

[a]Significance levels ≥ 0.08 are indicated by NS.

Table 35. Analysis of variance of BAS samplers from Big East Fork and Canyon Creek by taxa for the four week colonization period.

	Level of Significance[a]		
Variable	Creek	Site	Creek x Site
Elmidae	NS	NS	NS
Chironomidae	0.035	NS	NS
Corynoneura sp.	0.001	NS	NS
Eukiefferiella sp.	0.071	NS	NS
Baetis sp.	NS	NS	NS
Ephemerellidae	NS	NS	NS
Drunella sp.	NS	NS	NS
Serratella sp.	NS	NS	NS
Heptageniidae	NS	NS	NS
Cinygmula sp.	NS	NS	NS
Epeorus sp.	0.016	NS	NS
Rhithrogena sp.	0.042	NS	NS
Paraleptophlebia sp.	NS	NS	NS
Ameletus sp.	0.001	NS	NS
Mesocapnia sp.	NS	NS	NS
Nemouridae	NS	0.003	NS
Visoka cataractae	NS	NS	NS
Zapada sp.	0.001	NS	0.075
Calineuria californica	NS	0.010	NS
Perlodidae	NS	NS	NS
Hydropsychidae	0.081	NS	NS
Lepidostoma sp.	NS	NS	NS
Ecclisomyia sp.	0.012	NS	NS
Rhyacophila sp.	NS	NS	NS

[a]Significance levels ≥ 0.1 are indicated by NS.

The mean number of Ephemeropterans was significantly higher ($P \leq 0.043$) in Canyon Creek than in BEF with no significant difference relative to dredging (Table 34, Figure 27). Abundance of Ephemeropteran taxa varied with creek and site (Table 35). Epeorus sp., Rhithrogena sp., and Ameletus sp. mean number per sampler were significantly different for Canyon Creek ($P<0.016$, $P<0.043$, $P<0.001$, respectively) with no difference attributable to dredging. Other Ephemeropteran taxa means tested were not different for creek and site.

The mean number of Plecoptera per BAS sampler was not significantly different between creeks or sites (Table 34, Figure 28). Some plecopteran taxa varied significantly by creek and site (Tables 32 and 35). Mean number of Nenouridae per sampler was significantly higher ($P \leq 0.003$) above dredge in BEF. Mean number of Zapada sp. was higher above dredge in BEF samplers and lower in above dredge samplers in Canyon Creek. Mean number of Calineuria californica per sampler was higher ($P \leq 0.10$) below dredge in both Canyon Creek and BEF. Other Plecopteran taxa means tested for creek by site were not significantly different.

The mean number of Trichoptera per sampler in Canyon Creek was significantly higher ($P \leq 0.053$) than in BEF, but there was no significant difference by site in either creek (Table 34, Figure 28). Ecclisomyia sp. were significantly more abundant ($P \leq 0.012$) in Canyon Creek.

The mean percentage of predators was not significantly different for creek or site (Figure 29). A significant ($P \leq 0.001$) interaction for shredders indicated a higher percentage composition of this trophic group in BEF above dredge samplers, and a lower composition in Canyon Creek above dredge samplers, than for samplers below dredge in both creeks (Table 34). Mean percentage grazers was significantly higher ($P \leq 0.008$) in Canyon Creek BAS samplers (Table 34, Figure 30). Mean percentage gatherers was not significantly different between creeks or sites. A significant ($P \leq 0.021$) interaction indicated mean percentage filterers was higher above dredge in both creeks than below (Figure 30).

Sediment and Organic Material

Sediment content in BAS samplers was highly variable (Figure 31). Mean sediment content was significantly ($P \leq 0.048$) higher in samplers below dredge in BEF than above, with no significant difference in time. A significant ($P \leq 0.025$) interaction (creek by site) indicated sediment levels were relatively higher in samplers in Canyon Creek below BEF than in BEF below dredge when compared to samplers above dredge at both sites. No significant differences in organic matter with time for BEF samplers were observed; organic matter was significantly higher in samples below dredge ($P \leq 0.001$) than above. Mean organic matter content (Figure 31) was significantly ($P \leq 0.003$) higher in BEF samplers than in Canyon Creek samplers, and in below dredge samplers ($P \leq 0.002$) for both creeks.

Environmental Variables

Independent habitat variables of depth, velocity, organic matter, and sediment were not highly correlated and were used to analyze specific taxa (Table 36). Environmental variables accounted for 17 to 65% of the variation observed for specific taxa (Table 37). All regression models were significant except for Ameletus. The significance levels and multiple regression coefficients are reported in Table 38.

Table 36. BAS sampler independent variable correlation matrix.

	Depth	Velocity	Organic matter	Sediment
Depth	1.000	--	--	--
Velocity	0.0421	1.000	--	--
Organic matter	0.0424	0.1154	1.000	--
Sediment	-0.1951	0.1381	0.4739	1.000

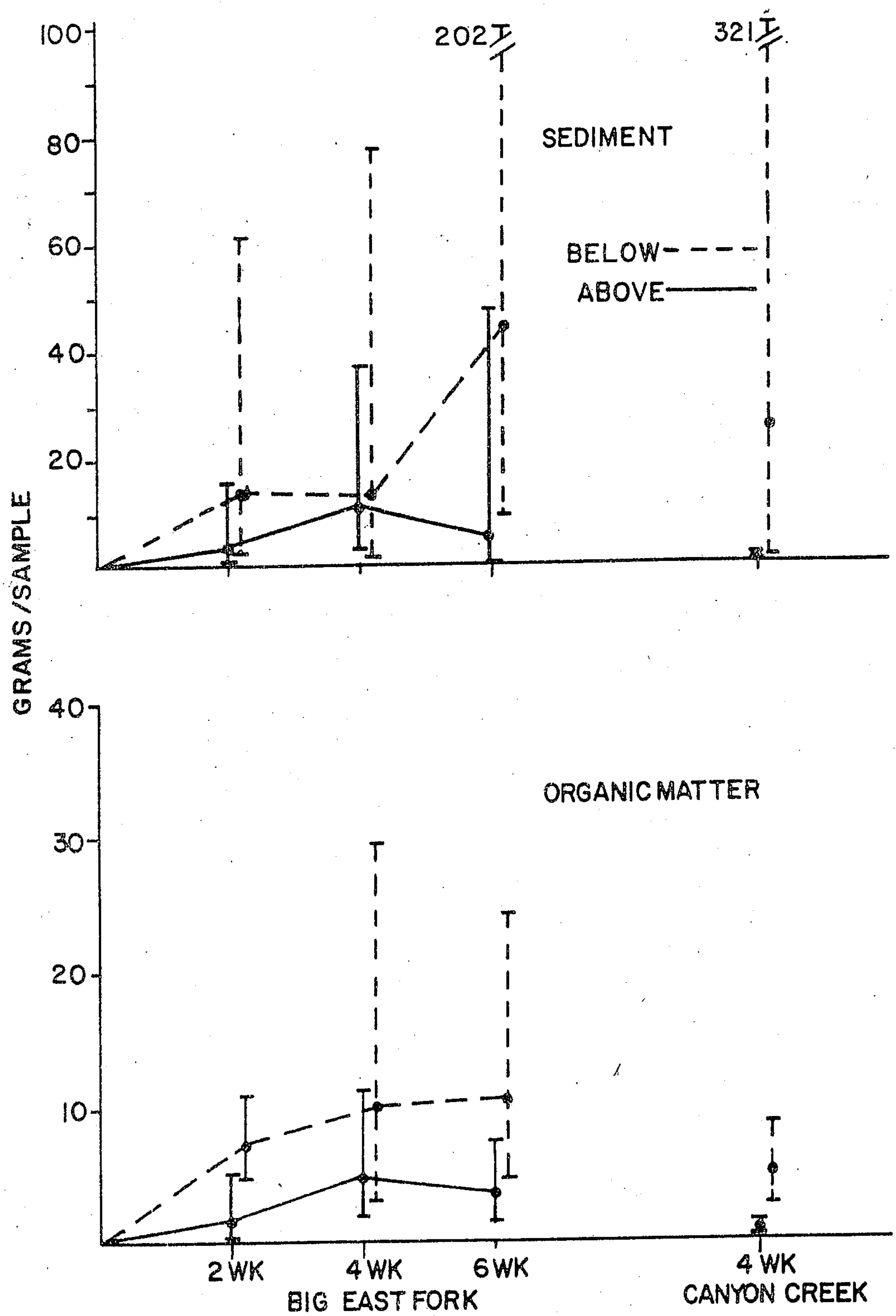

Figure 31. Mean weight and 95% confidence limits for sediment and organic matter in BAS samplers above and below dredge. Mean of 7 samplers.

Table 37. Overall significance of multiple regression equations for major taxa collected in BAS samplers in relation to water depth, velocity, organic matter, and sediment.

Variable	Transform[a]	Multiple R	Multiple R^2	Sig.
Annelida	2	0.804	0.647	0.001
Corynoneura sp.	1	0.537	0.289	0.001
Eukiefferiella sp.	1	0.647	0.419	0.001
Baetis sp.	1	0.720	0.518	0.001
Serratella sp.	1	0.410	0.168	0.048
Cinygmula sp.	1	0.492	0.242	0.006
Epeorus sp.	1	0.413	0.170	0.046
Rhithrogena sp.	1	0.650	0.422	0.001
Paraleptophlebia sp.	1	0.448	0.200	0.020
Ameletus sp.	All	--	--	NS
Mesocapnia sp.	None	0.481	0.231	0.008
Zapada sp.	1	0.584	0.341	0.001
Calineuria Californica	1	0.471	0.222	0.011
Perlodidae	1	0.471	0.222	0.011
Hydropsychidae	1	0.613	0.375	0.001
Lepidostoma sp.	1	0.473	0.224	0.011
Rhyacophila sp.	1	0.482	0.232	0.008

[a]Transformation 1. = log(y+1), 2. = sq. rt. (y+1).

Table 38. Multiple regression coefficients and significance levels. Vel, Velocity; Orgmat, Organic Matter; Sed, Sediment.

	Habitat variables and significance[a]							
Variable	Depth	Sig	Vel	Sig	Orgmat	Sig	Sed	Sig
Annelida	0.17	0.05	-0.60	NS	0.45	0.01	0.50	0.01
Corynoneura sp.	0.04	NS	0.54	0.01	-0.01	NS	-0.11	NS
Eukiefferiella	-0.01	NS	0.63	0.01	0.14	NS	-0.12	NS
Baetis sp.	-0.11	NS	0.66	0.01	-0.29	0.01	0.23	0.06
Serratella sp.	-0.05	NS	0.18	NS	-0.40	0.01	0.03	NS
Cinygmula sp.	0.14	NS	0.27	0.03	-0.45	0.01	0.35	0.02
Epeorus sp.	0.14	NS	0.26	0.05	-0.36	0.02	0.10	NS
Rhithrogena sp.	0.07	NS	0.54	0.01	-0.39	0.01	0.33	0.01
Paralepthophlebia	-0.01	NS	-0.13	NS	0.33	0.03	0.18	NS
Ameletus sp.	--	NS	--	NS	--	NS	--	NS
Mesocapnia sp.	-0.10	NS	0.09	NS	-0.07	NS	0.46	0.01
Zapada sp.	-0.19	NS	0.54	0.01	-0.10	NS	-0.23	0.09
Calineuria californica	0.42	0.01	0.14	NS	-0.18	NS	0.30	0.04
Perlodidae	-0.18	NS	0.36	0.01	-0.29	0.05	0.13	NS
Hydropsychidae	0.02	NS	0.57	0.01	-0.26	0.04	0.16	NS
Lepidostoma sp.	0.09	NS	-0.08	NS	0.50	0.01	-0.13	NS
Rhyacophila sp.	0.04	NS	0.42	0.01	-0.11	NS	0.23	NS

[a]Significance levels >0.05 are indicated by NS.

Kick and Drift Samples

Most taxa found in kick samples were also collected in BAS samplers (Table 26). Taxa present in drift and kick samples, but not in BAS samplers were Stenelmis sp. and Carabidae. Taxa found only in kick samples included: Glutops sp., Tabanidae (genera unseparable), Hexatoma sp., Orohermes crepusculus, Megarcys sp., Perlinodes aurea, Perlodidae (undescribed genera), and Tinodes sp. Geometric mean Shannon-Weaver indices calculated for BAS samplers (Figure 26) were lower than arithmatic mean indices derived for kick samples (Table 39). Means for untransformed Shannon-Weaver indices for 6-week colonization periods were similar to kick samples (3.58 and 3.60 for BEF above and below dredge, respectively). Equitability Indices were more variable (Table 31). Percentage composition of grazers in kick samples was similar to their composition in BAS samplers, while percentage gatherers were lower in kick samples than in BAS samplers (Table 39 and Figure 29). Composition of filterers and shredders in kick samples was highly variable and indicated no clear trends (Table 39). Percentage composition of predators was consistently higher in all kick samples than in BAS samplers (Figure 30).

All invertebrate taxa captured in drift samples were common to kick and BAS samples (Table 26). Density of drift organisms was highest at 2200 hours. The most common taxa in drift samples consisted of: Chironomini, Eukiefferiella sp., Baetis sp., and Zapada Columbiana. Drift periodicity of functional feeding groups is presented in Figure 32. Gatherers were the most abundant functional group in drift samples, and were markedly higher in number below dredge in BEF. Gatherers were slightly more numerous above dredge than below in Canyon Creek.

Table 39. Kick sample analysis for diversity indices and percentage functional group composition. E, Equitability Index; H', Shannon-Weaver Diversity Index; Pred, Predators; Shred, Shredders; Graz, Grazers; Gath, Gatherers; Fil, Filterers.

			Percent				
Site	E	H'	Pred	Shred	Graz	Gath	Fil
Big East Fork above dredge (1)							
Week two	0.67	2.86	25	8	3	64	0
Week four	0.89	3.54	44	16	0	39	2
Week six	0.68	3.55	23	13	6	57	2
Big East Fork below dredge (2)							
Week two	0.80	3.11	26	0	2	57	15
Week four	0.68	3.43	23	29	1	45	2
Week six	0.78	3.83	13	18	2	62	7
Canyon Creek above BEF (3)							
Week four	0.74	4.16	19	11	4	63	3
Canyon Creek below BEF (4)							
Week four	1.00	3.01	45	0	0	52	3

Water Quality

Canyon Creek discharge ranged from 4.06 m^3/s to 0.84 m^3/s and BEF discharge 0.22 $m^3/2$ to 0.08 m^3/s during the invertebrate study. Conductivity, temperature, and turbidity varied with sampling site and time (Figure 33). Conductivity was consistently higher in BEF. Turbidity was higher just below dredge than at all other sites, and during dredging exceeded 15 NTU. Diel temperature varied 2°C and 0.6°C in BEF and Canyon Creek, respectively. The following significant ($\underline{P}\leq 0.05$) regressions were determined for turbidity, settleable solids, and flow:

$$T = 0.2042 + 0.0021\ Q$$

$$S\text{-}CC = 0.3611 + 1.4043\ T\text{-}CC$$

$$S\text{-}BEF = -6.6524 + 26.5708\ T\text{-}BEF$$

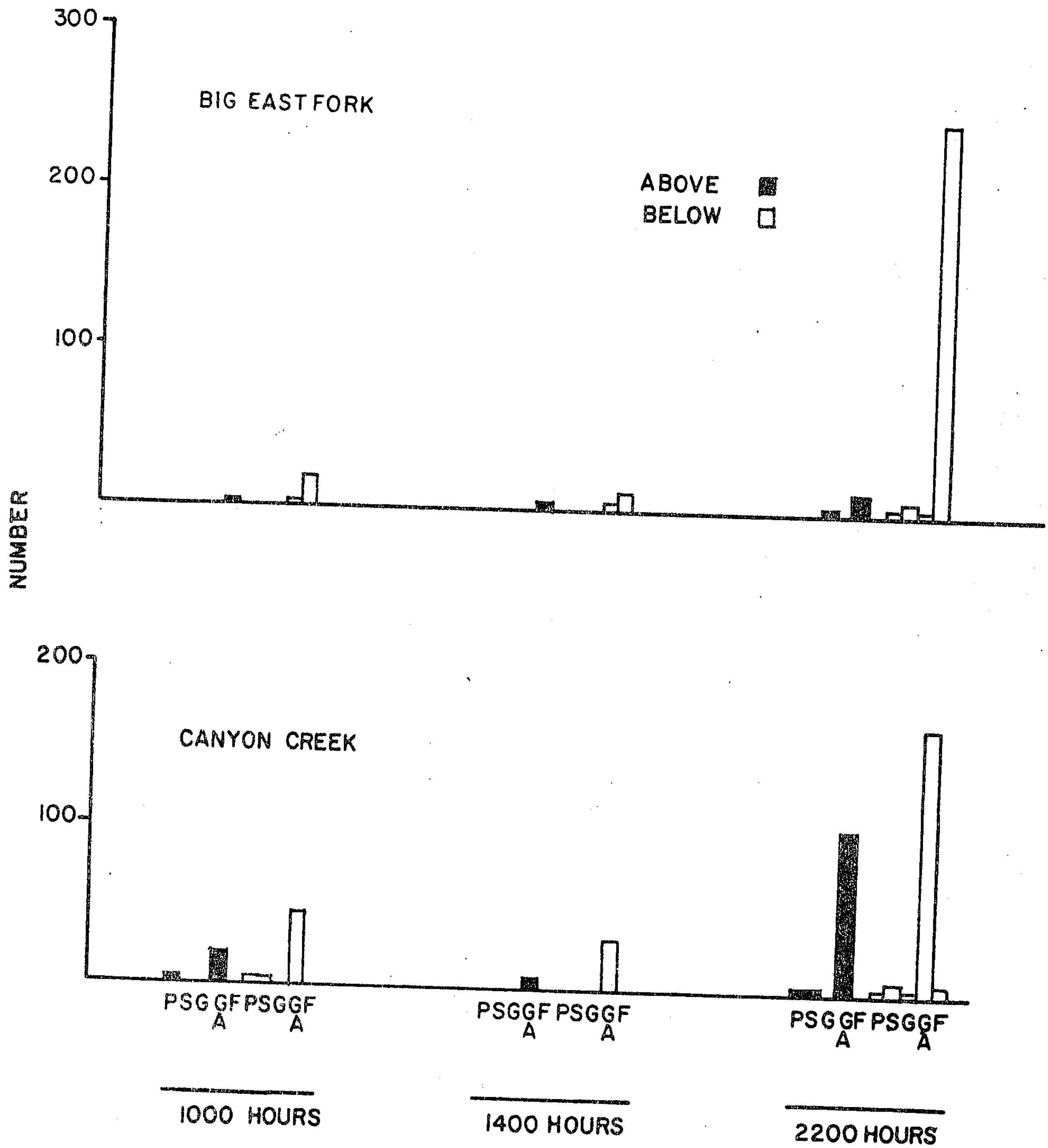

Figure 32. Numbers of functional feeding groups captured in drift samples at 1000, 1400 and 2200 hours October 8, 1983.

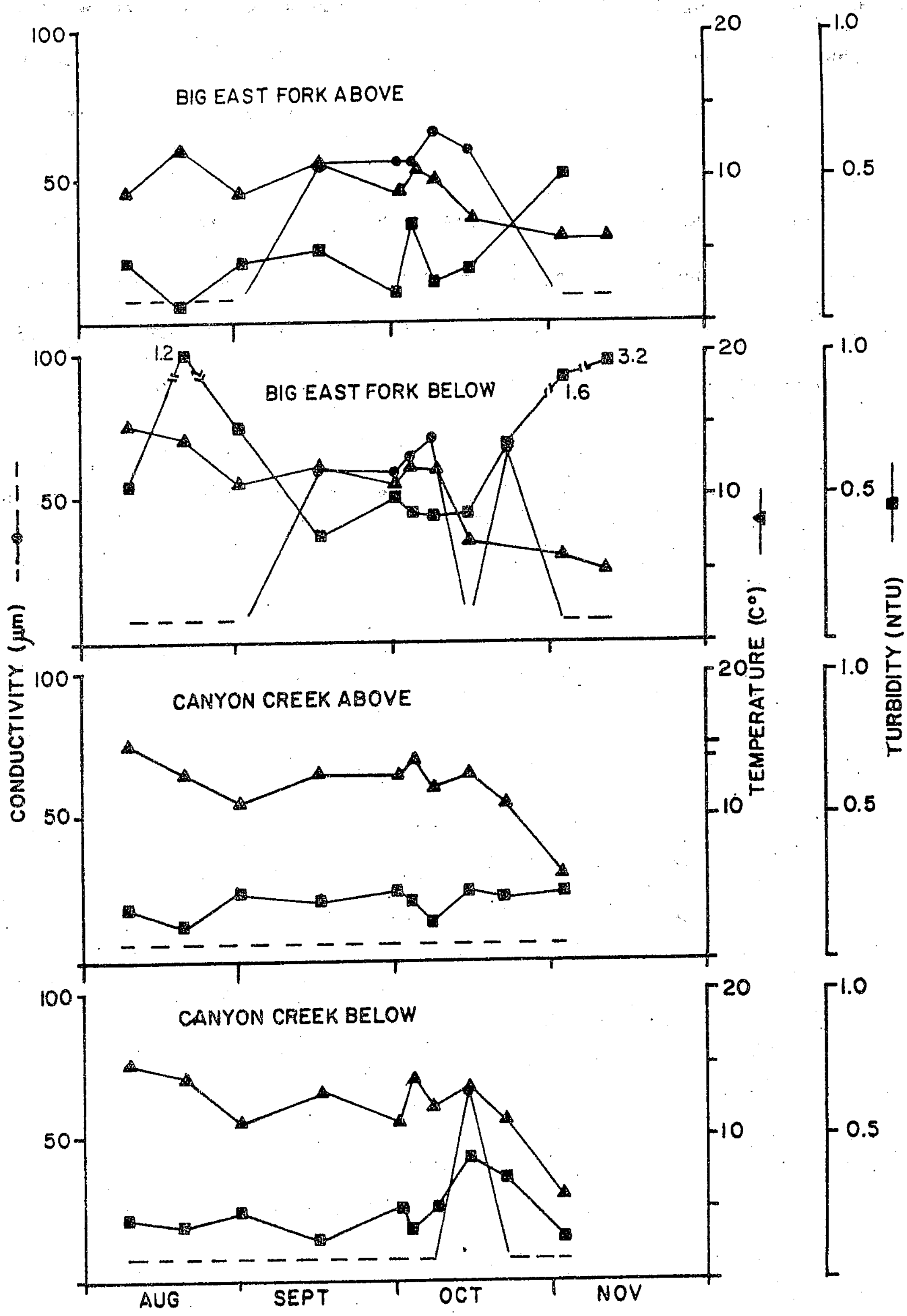

Figure 33. Water conductivity, temperature and turbidity at invertebrate study site above and below dredge, 1983.

Where: BEF = Big East Fork, CC = Canyon Creek, Q = streamflow (c ft^3/s), S = settleable solids (mg/l), and T = turbidity (NTU). The settleable solids equations are for time and site combined. There was no significant relation between suspended solids and flow.

Increased sedimentation, measured with sediment traps, due to suction dredge mining appeared localized to BEF (Figure 34). Extrapolation of sedimentation rates from sediment trap data gave the following results: BEF above dredge site 1, 29 g/m^2/day; BEF above dredge site 2, 23 g/m^2/day; BEF 40 m below dredge, 1711 g/m^2/day; BEF 113 m below dredge, 698 g/m^2/day. Composite size fractions of dredge mining sediment sampled with traps indicated particle sorting as a function of downstream distance (Figure 35).

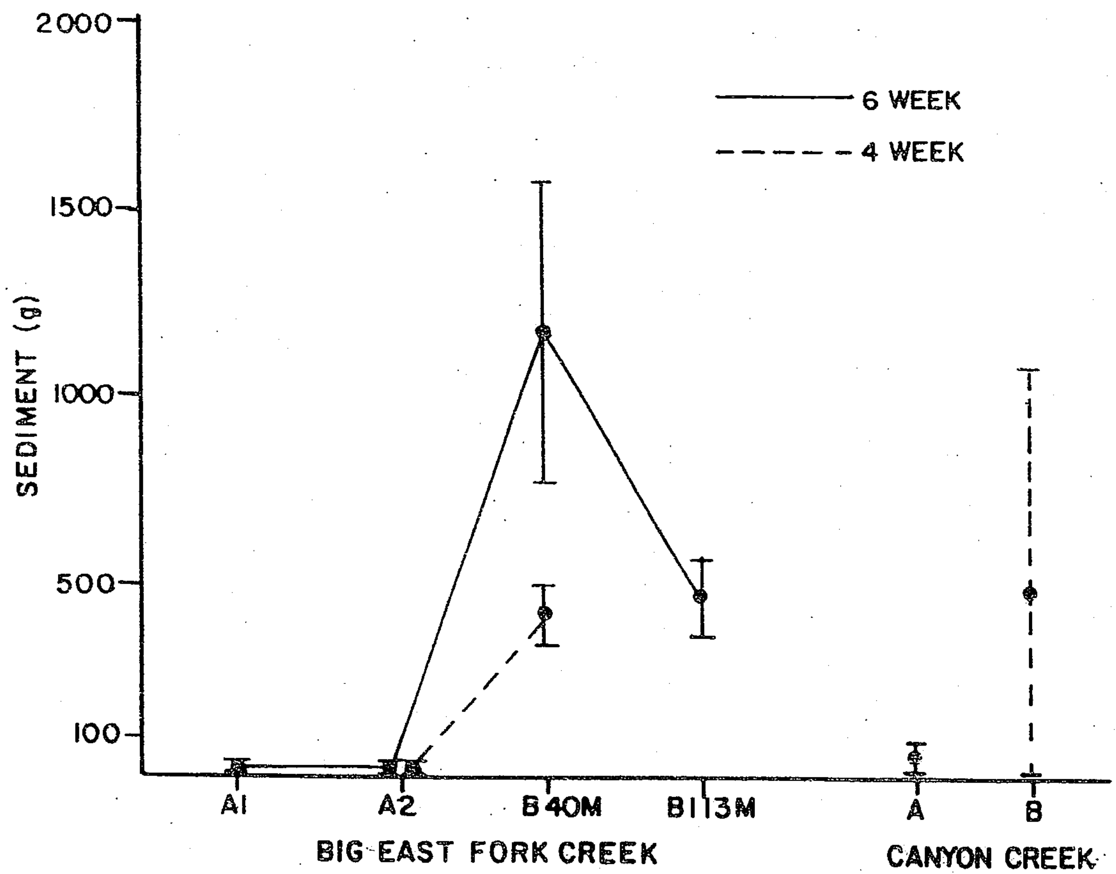

Figure 34. Mean weight and standard error of sediment deposited in sediment traps at 4 and 6 weeks above (A1, A2) and below (B 40 meters, B 113 meters) dredge. Mean of 6 traps.

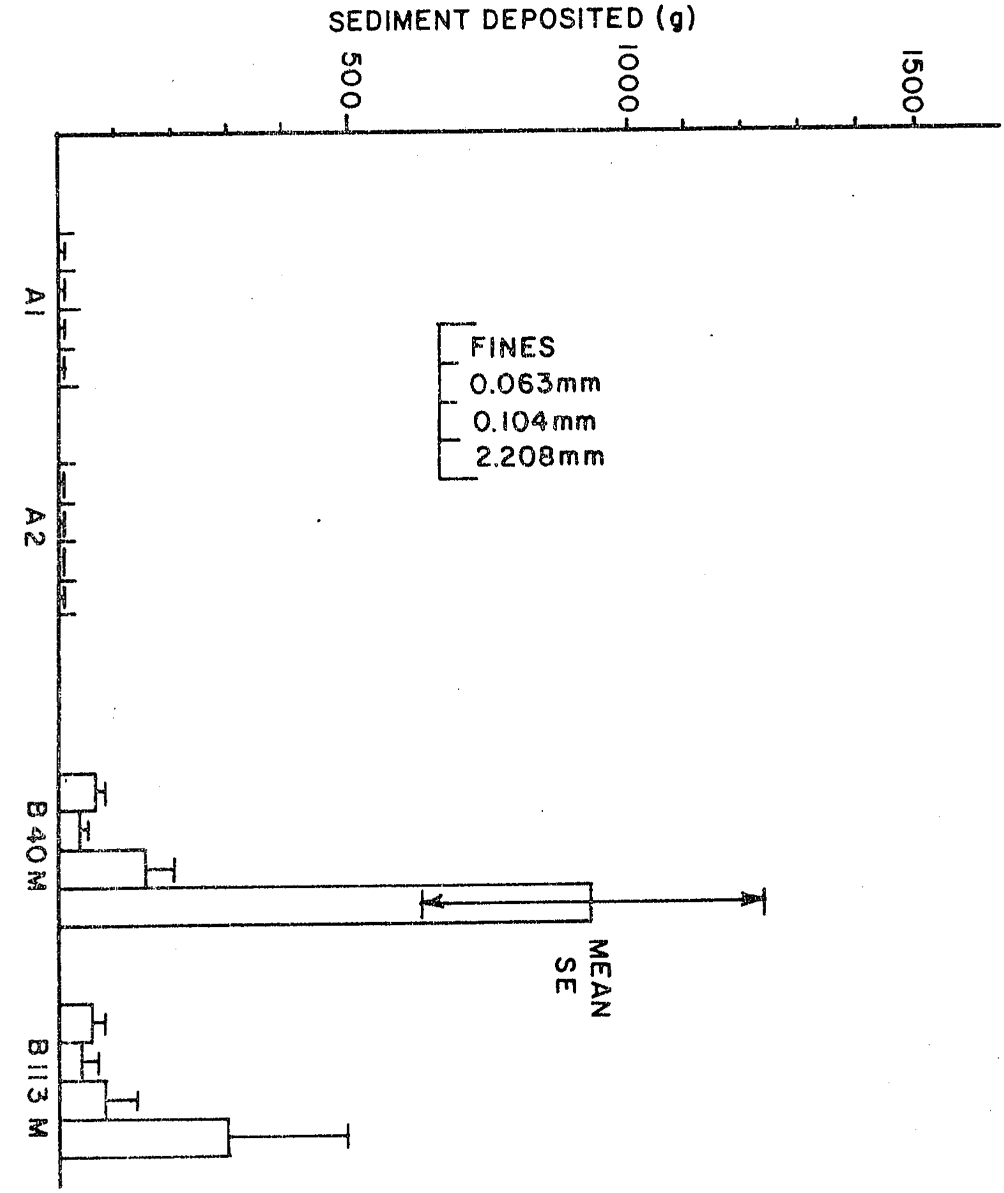

Figure 35. Mean weight and standard error of sediment by particle size in sediment traps at 6 weeks above (A1, A2) and below (B 40 meters, B 113 meters) dredge, Big East Fork Creek, Trinity County, California. Mean of 6 traps.

DISCUSSION

Suction Dredge Mining

The majority of suction dredge operators in Canyon Creek did not work long periods or disturb large areas of the streambed. Dredging impacts upon the channel geomorphology were confined to the area dredged and the area immediately downstream. However, since a number of suction dredges operated during the 1984-1985 seasons, a total of over 1000 m^2 of streambed was disturbed each year. Water quality was impacted only during the actual operation of a suction dredge. Since a full day of mining by most Canyon Creek operators included only 2 to 4 hours of dredge running time, water quality was impacted for a short time. Dredges operating within 0.5 km of another did infrequently result in cumulative impacts upon water quality. Cumulative impacts of 2 or 3 dredges in the same reach of stream did not compound geomorphic impacts upon the channel bottom, but may have contributed to heightened channel instability if stream bank areas were undercut, sluiced or altered.

Winter and spring flushing flows filled in dredge holes and dispersed tailing piles. Only the three largest dredge operations from 1984 had any substantial remains visible in 1985. The largest remnant of the 1984 season was located in a side channel of Canyon Creek. Its distance from the thalweg permitted the mining disturbance to persist through the 1985 water year. The dredge operation with the second largest remains was the deepest hole excavated on the stream. The depth of this hole and the large area encompassed by it allowed traces of dredging activity to endure the winter and spring flushing flows. At the third site, large cobbles and gravels were piled along the stream's edge and these rocks remained along the bank after high flows.

During the study some dredgers undercut banks, channelized the stream, and damaged the riparian. Although not all of these cases would have warranted an infraction, these dredgers did not abide with current dredging codes (Fish and Game Code, Sec. 1603, 1982). In Sierra foothill streams, McCleneghan and Johnson (1983) observed a much smaller percentage of suction dredge miners adversely impacting the stream and its resources. Adverse operational impacts were probably more extensive in Canyon Creek due to its relatively small size and miners working the edges of the channel. Dredging the stream bank frequently resulted in channelizing the stream to maintain adequate water flow in the working area, bank undercutting, and removing streamside vegetation to access the area. The damage to the streambank destablized the channel and accelerated bank erosion.

Dredge tailings are often referred to as good salmonid spawning substrate. In the Trinity River, chinook salmon have been observed spawning in the tailing piles of suction dredges (E. Miller pers. comm.). Steelhead in Idaho streams have been reported to spawn in gravels recently disturbed by human activities (Orcutt et al. 1968). In the American River, Prokopovich and Nitzberg (1982) have shown salmon spawning gravels have mostly originated from old placer mining operations. In Canyon Creek, gravel dredge tailings dispersed by high streamflows certainly make-up a component of the suitable spawning substrate, however, no salmonid redds were ever found exclusively in a dredge tailing pile. In general, tailing piles were judged as undesirable spawning areas. Deposited during low summer flow, dredge tailings are very unstable features. Since tailing materials are sitting on top of the streambed, slight increases in stream volume and velocity are capable of mobilizing these gravels. Salmonid redds constructed in loose gravel are susceptible to scour and often result in direct loss of spawn (Gangmark and Bakkala 1960). The longitudinal bottom profile at dredge hole 15 demonstrated the erodability of tailing piles during a normal water year.

The complete lack of fines and well-sorted nature of tailing piles also contribute to the undesirability of these areas for salmonid spawning. Platts et al. (1983) found that spring and summer chinook in the Salmon River drainage of Idaho did not select channel substrates complete devoid of fine sediment. The "weathering" of gravel, required for acceptance by salmonid spawners (Reeves and Roelofs 1982), may be important for substrate stability and embryo survival (Platts et al. 1983).

The monitoring of localized impacts upon channel geomorphology provided some insights to the effects of suction dredge mining upon salmonid rearing habitat. The accumulation of tailings on the streambed immediately below the dredges reduced the channel's x-sectional area and living space for fish. In Knapp Creek, Idaho, Bjornn et al. (1977) demonstrated that the loss of pool volume from sediment addition resulted in a proportional decrease in fish numbers. However, during the suction dredge mining process, a new pool area is created by the cone-shaped dredge hole. Dace, suckers and juvenile steelhead were observed feeding and resting in Canyon Creek dredge holes. Freese (1980) observed a small spring-run chinook salmon holding in a dredge-created pool on Canyon Creek.

Since many in-stream areas of Canyon Creek lack aquatic vegetation, large organic debris, and riparian cover, the streambed substrate is extremely important for rearing salmonid cover. Newly emerged salmonids tend to hide beneath bottom substrate (Hartman 1965). Boulders and other large rocks in the substrate create "focal points" for juvenile salmonids from which they retain territory and venture to feed (Wickham 1967). The relative importance of cover is illustrated by experiments by Boussu (1954) and Elser (1968) in which salmonid abundance declined when cover was reduced. High quantities of deposited sediment 10 to 16 m below dredges in Canyon Creek markedly decreased the amount of instream cover. Fine sediment filled gravel interstices and stream bottom roughness declined in below dredge areas. Reduced substrate particle sizes and increased levels of embeddedness also reflect the diminished quality of salmonid rearing habitat due to instream cover losses. Harvey et al. (1982) found sculpin densities reduced up to 50 percent below suction dredges due to increased cobble and boulder embeddedness.

Suspended sediment can adversely effect salmonids by abrading and clogging gills, reduce feeding, and cause avoidance of turbid areas (Cordone and Kelley 1961). In

Canyon Creek, suspended sediment and turbidity levels were higher than ambient levels immediately below suction dredges, but did not approach levels that would damage gill surfaces. Suspended sediment and turbidity levels declined very rapidly downstream of mining, so fish could avoid the most silt-laden waters. As stated previously, diminished water quality only occurred when a dredge was operated.

Channel Morphology and Water Quality

The annual variation of streamflow in Canyon Creek works to the advantage of the suction dredge miner. Low summer flows create ideal conditions for dredge mining by providing relatively easy access to placer deposits in the stream channel and enough water to float and operate a dredge. High winter flows transport material and fills-in dredge holes, disperse tailing piles and redistributes gold deposits.

Variation in the quality of anadromous salmonid spawning and rearing habitat in the study area was reflected by the different channel configurations and flow characteristics at each cross-section. The low gradient, wide channel and medium-size gravels of the stream reach at the lower x-section provided good salmonid spawning habitat; however, sparse overhead cover, unstable banks, and the lack of pools offered poor rearing habitat. The moderate gradient, large gravels, good overhead cover, and well-defined channel at the mid-stream x-section provided the best salmonid rearing habitat in the study area. Runs, riffles, and shallow pools at meanders offered a good diversity of in-stream habitat for rearing and spawning. The high gradient, boulder strewn channel at the upper stream x-section offered limited rearing and spawning habitat for salmonids. Some shallow pools occur between rapid runs and riffles; but, in general, velocities were high for fry and juveniles. With the exception of a few gravel pockets behind large boulders, the steep gradient and high velocity waters have removed small streambed materials. Some steelhead did spawn in the larger gravel pockets, but little spawning habitat was available.

The large substrate and fast water also present difficult working conditions for suction dredge operations in the upper stream study area.

Channel degradation was about equal to channel aggredation at the mid and upper stream x-sections suggesting that the channel was relatively stable in those areas. The channel at the lower stream x-section, which had a net degradation, appeared to be unstable due to erosion of a constructed gravel berm and bank wasting.

The water quality of Canyon Creek was very good and only affected by suction dredging near the dredge when it was operated. In comparison to other Trinity River tributaries, Canyon Creek has excellent water clarity (Calif. Dept. Water Resources 1980). Turbidity, suspended sediment, conductivity, and total dissolved solids were low during the study. The greatest amount of sediment produced in the drainage was not by suction dredging but by surface placer miners that sluiced tailings into the stream, debris that were dumped over the bank during the grading of a private road and when a substance used to flocculate suspended silt in a settling pond of a high bar mining operation leeched through the banks into the stream. The leaching increased turbidity and conductivity and impacted water quality downstream for 3 to 4 days. Some of these operations produced turibidities above 15 NTU that were detectable 4 miles downstream.

Stream temperatures in Canyon Creek were generally suitable for anadromous salmonids. During late July and early August, temperatures near the mouth of Canyon Creek approached the upper lethal limit for rainbow trout (McAfee 1966) and salmon (Brett 1952). However, since the stream cooled 5^{o} to $8^{o}C$ each night, the duration of the high temperatures was short and localized. Seepage into the stream from groundwater and substream flow provided pockets of cooler water in the summer months. Stream temperatures in the study area were generally well within the recommended ranges for spawning, incubation, and rearing of salmonid fishes (Reiser and Bjornn 1979) and dredge mining had little, if any, impact on water temperature.

Dredging and Invertebrates

Artificial substrate samplers reduce bias, standardize sampling and require fewer samples than other benthic samplers for a given coefficient of variation (Crossman and Cairns 1974; Dickson et al. 1971). The samplers collected a greater diversity and abundance of benthic organisms than the Peterson Dredge (Anderson and Mason 1968). Barbeque-basket substrates collected more organisms than flexiring or Hester-Dendy multiple-plate samplers, and species composition of the basket samplers was more similar to natural substrates than other artificial substrate samplers (Ferreira 1976). Artificial substrate samplers allow collecting from habitats difficult to sample by other methods, and permit nondestructive sampling of an environment (Rosenburg and Resh 1982).

One disadvantage of the artificial substrate sampler is the long exposure time needed for colonization (Rosenburg and Resh 1982). Stability in the number of taxa and specimens and the Shannon-Weaver Diversity index through time had not occurred after 9 weeks when using conservation-web substrates (Dickson and Cairns 1972). However, they noted that conservation-web substrates were not reliable for collecting quantitative data. Another disadvantage is that macroinvertebrates are often lost when artificial substrates are retrieved (Rosenburg and Resh 1982, Harrington 1983). We believed that our extraction technique minimized escape.

The number of invertebrates sampled with BAS samplers in BEF peaked between the two and four week periods. Total number of invertebrates had decreased at the six-week colonization period while diversity had correspondingly increased. Gore (1982) in a review of the literature found that maximum invertebrate density was reported for 21 to 30 day colonization periods and postulated a graphical presentation of increasing number of taxa with time that is similar in form to the colonization curve presented in Figure 6 for the Shannon-Weaver Index. He suggested that the equilibrium community was attained after achievement of maximum density through arrival of rare species and intraspecific competition.

Although basket-type samplers may be more representative of stream habitat than other artificial substrate samplers, these samplers are selective for organisms that colonize them (Rosenburg and Resh 1982). The BAS samplers in this study provided a small cobble habitat in deep riffles that was prevalent at all sites. Pool habitat was not sampled to reduce variation. Minshall and Minshall (1977) found that pool fauna contained no important taxa over those found in riffles, with the more diverse fauna in riffles. The absence of Orohermes crepusculus in BAS samplers from BEF was most likely due to an observed preference for larger cobble substrate. Crossman and Cairns (1974) suggest that aquatic invertebrates tend to selectively colonize areas with specific substrate characteristics.

Functional group composition was generally similar between BAS and kick samples for the 6-week colonization period. However, composition of predators was lower and shredders higher in BAS samplers when compared to kick samples for Site 1. Autumn funtional group composition for a third order Oregon stream was: shredders, 42%; collectors, 12%; grazers, 21%; filterers, 8%; and predators, 17% (Hawkins and Sedall 1981). Minshall (1981) reported: 33% grazers, 78% collectors (gatherers and filterers), with <5% filterers in numbers, for a third order Rocky Mountain stream. The low percentage of grazers in this study ($\leq$6%) may reflect low primary production and dependence on autochthonous input for the Canyon Creek Basin. Vannote et al. (1980) proposed that low order stream systems with photosynthesis/respiration ratios less than one would be composed of collectors, shredders, predators, and grazers in respective abundance.

Operation of suction dredges results in a pocket and pile stream morphology which impacts the physical and biological nature of the area. The two dredge holes in BEF were excavated to depths of 2 m and both holes filled in with stream substrate after high flows during winter. Siltation conditions at BEF below where dredging occurred remained about the same until high winter flows flushed the streambed. As suction dredge mining excavations in the Canyon Creek Basin commonly exceed a meter in depth, stream bed storage of organic matter could be substantially impacted within the localized dredged area. Cummins et al. (1981) report that peak organic matter storage was found in sediments 15 to 30 cm in depth for Oregon streams in old-growth forests. The bedload movement that filled the dredge holes in BEF may have restored some of the depented organic matter which is necessary for invertebrate colonization. Egglishaw (1964) found that the distribution of bottom fauna was significantly correlated with the distribution of plant detritus in the riffle.

Disturbed stream bottom, such as dredged areas in Canyon Creek Basin, are primarily recolonized by drift in 1-3 months (Lewis 1962; Waters 1964; Meeham 1971; Griffith and Andrews 1981). Thomas (1985) found invertebrates recolonized dredge holes less than 1 m deep within one month for all taxa except Tricoptera. She suggested that downstream sediment deposition may have impacted this group. Harvey et al. (1982) observed little recovery of Tricorythodes sp. and Chloroperlidae two weeks after dredging ceased.

The impacts of dredging on benthic organisms must be viewed with regard to BAS sampler colonization dynamics. In this context, silt-free uncolonized habitat was introduced into a stream ecosystem with seasonally abnormally high sedimentation and organic input levels. This process was exemplified by mean number of invertebrates per BAS sampler in which the below dredge BAS sampler population peaked before the above dredge BAS population. The rapid increase in suitable microhabitat found in BAS samplers below dredge areas, due to high siltation levels, would result in accelerated colonization.

Benthic invertebrate abundance did not increase at stations downstream of dredging in BEF and Canyon Creek. Thomas (1985) found no increase in invertebrate density downstream of gold dredging and attributed this to increased predation by fish, and inability of invertebrates to locate suitable habitat. During diving surveys, we observed

Salmo gairdneri congregating and selectively feeding on benthic invertebrates displaced by dredging.

The impacts of dredging at BEF did not result in differences for Shannon-Weaver diversity indices above and below the dredge activity. Mean diversity indices for all BAS sites were well within the range (2.60 to 4.00) found for "healthy" streams by Wilhm (1970). In heavily silted experimental stream channels Brusven and Prather (1974) found short term decreases in diversity. In moderately silted Knapp Creek, Idaho, the overall insect community was not affected, but particular species were adversely affected. Benthic insect diversity was adversely affected when cobble imbeddedness exceeded 66% in Elk Creek, Idaho (Bjornn et al., 1977).

The number of Annelids increased with time at the below dredge sites in Canyon Creek and BEF with no similar increase observed at above sites. Increased sediment and organic matter deposited in BAS samplers below dredging provided enhanced habitat and Annelid abundance increased.

The total number of invertebrates and Diptera were greater in below dredge samplers earlier (2 and 4 week periods) than in above dredge samplers. However, at the 6-week colonization period, the numbers of Diptera per BAS sampler at above and below dredging sites were similar. The numerically dominant Dipterans, Eukiefferiella sp. and Corynoneura sp., were gatherers, a functional group observed by Gore (1982) as initial habitat colonizers.

Ephemeropterans showed no overall negative response to dredging. Baetis sp. numbers showed a significant positive relationship to sediment. Heptageniid taxa showed similar responses to sediment, along with a preference for high velocities. Harvey (1982) found no changes in abundance of Baetis sp. below dredging and suggested that the deposited substrate may have been as suitable as the prior cobble substrate. Ecological niche requirements for Ephemeropterans may be broad enough that moderate siltation levels do not impact populations.

Plecopteran taxa showed varied responses to dredge mining and Trichopterans showed no significant response. Numbers of Zapada sp. were reduced at below dredge sites, which may be a result of their avoidance of sediment loads, they had an inverse relationship with sediment. Calineuria californica abundance was higher below dredging, and had a significant relationship with depth and sediment. Harvey (1982) found increased numbers of Calineuria sp. below dredging and suggested that the siltation from dredging may cover hiding places and render prey more accessible to predators such as Calineuria. Increased homogeneity of substrate made aquatic insects more susceptible to predation by Cottus rhotheus (Brusven and Rose 1981). Analysis of Trichopteran taxa illucidated colonization trends resulting more from colonization dynamics than dredging impacts.

Functional group analysis illucidated trophic responses to dredging impacts of pooled taxonomic groups that were individually sparse. Grazer numbers showed a gradual increase in time that was higher at the above dredge sites. Grazers feed upon periphyton, and it is possible that silt limited periphyton production or grazer access at below dredge sites. Hynes (1974) reported that siltation smothered algal growth. Composition of gatherers at below dredge sites was higher than at above sites. This may have resulted because more organic matter was present below dredging, along with a tolerance of gatherers to silty substrates. Filterers quickly colonized the new habitat provided by BAS samplers, but decreased in number at below dredge sites as siltation increased. Harvey (1982) found Hydropsyche sp. numbers severely reduced below dredging operations, and noted a reduction of clean cobble habitat in these areas. High sediment load clogged cone shaped nets constructed by Cheumatopsyche sp. and inhibited feeding (Gammon 1970). Shredders were more abundant at above dredge sites. Preferred leaf matter and shelter for these taxa were probably covered with silt below dredging. Cummins (1974) noted a nutritional dependence by shredders on the microbial flora on the organic substrate rather than the substrate itself.

Ecological differences between Canyon Creek and BEF were more important than suction dredge mining impacts on benthic invertebrates. However, specific taxonomic groups in Canyon Creek responded to dredge mining impacts from BEF. Grazers were more abundant in Canyon Creek due to increased sunlight from more open stream and therefore higher periphyton growth. Shredders were more numerous in BEF apparently due to greater canopy coverage which resulted in higher leaf matter input into BEF. Leaf pack input into Canyon Creek from BEF may have increased shredder abundance in Canyon Creek below BEF. Differences between creeks were significant on the ordinal level, while no differences were observed between above and below sites on Canyon Creek. Annelids were more numerous in Canyon Creek below BEF as a result of increased silt load. Nemourids were more abundant in the upper Canyon Creek site, probably a result of leaf pack siltation at the lower Canyon Creek site. Increased prey availability, discussed previously, may have enhanced C. californica populations which were more numerous in Canyon Creek below BEF. Thomas (1985) found no downstream impacts to invertebrates from a 6.4 cm diameter dredge operated in Gold Creek, Montana. BEF appeared to contain a higher proportion of fines, steeper gradient, and more extensive dredging than occurred in Gold Creek, Montana.

The sedimentation that resulted from suction dredge mining in BEF appeared to have little influence on benthic invertebrate drift in BEF for all functional groups except gatherers. The abundance of gatherers in drift may have resulted from excess production in BEF below the dredge site or may have resulted from the dredging. Entrainment and subsequent drift of invertebrates as the result of suction dredge mining has been observed (Lewis 1962; Griffith 1981). Gammon (1970) observed increasing sediment concentration elevated drift rates, while Bjornn et al. (1977) found no relationship. Pearson and Franklin (1968) postulated that turbidity reduced light penetration in the water column and triggered behavioral drift.

Turbidity plumes created by gold dredging in BEF were visible in Canyon Creek, a distance of 123 m downstream. Lewis (1962) observed a 61 m plume below a 12.7 cm dredge. Griffith (1981) found low turbidities below a 7.6 cm dredge used in two Idaho streams. Turbidity levels in BEF were higher below dredging and peaked at 15 NTU. Harvey (1982) observed turbidities to 50 NTU resulting from gold dredging and LaPerriere (1984) measured turbidity levels of 1665 NTU in Alaskan streams. There has been concern that high turbidity levels adversely affect feeding activity by salmonids. Sigler et al. (1984) found that salmonids subjected to continuous turbidities of 25 NTU had lower growth than control fish. Brusven and Rose (1981) found no affect of suspended sediment on feeding by *Cottus rhotheus*. Harvey (1982) observed no deleterious affects on salmonid feeding from suction dredge siltation.

Suction dredging may have an affect on silt deposition, temperature and conductivity. At the Canyon Creek and BEF sites, there was a significant relation between settleable solids and turbidity, but there was no relation when the the sites were pooled. Duchrow and Everheart (1971) found a high correlation between turbidity and weight for individual sediment types, although it varied between sample and station. Temperatures above and below dredging sites in Canyon Creek and BEF were virtually identical, indicating no apparent impact on water temperature from dredging. Casey (1959) found dredged stream sections had higher temperatures than controls. Conductivity levels at all sites in Canyon Creek Basin varied near 50 micromhos.

Welton and Ladle (1979) believed that sediment traps could not give net rates of sedimentation, but rather give an estimate of the amount of material potentially available to settle on a particular area. The peak sedimentation rate below the dredge in BEF (1711 $g/m^2/day$) was comparable to estimates derived by Harvey et al. (1982) for the North Fork American River, CA (2070 $g/m^2/day$) and by Thomas (1985) (1720 $g/m^2/day$) for Gold Creek, MT. In BEF, 21% (by weight) of sediment trapped 50 m below the dredge was less than 0.1 mm and at 113 m, 38%. Griffith and Andrews (1981) found that fine sediment less than 0.5 mm in diameter comprised up to 18% by weight of the overburden dredged.

Sediment in BEF had not returned to background levels at 113 m downstream of the dredge, and had slightly impacted the lower Canyon Creek site. Thomas (1985) noted that the bulk of sediment deposition occurred within 20 m downstream of the dredge, however, sediment levels had not returned to background levels at 30 m. Harvey et al. (1982) observed sediment deposition to 60 m downstream. In BEF sediment from dredging was displaced further downstream than in other studies because of the steeper stream gradient, and a higher proportion of fines released in the overburden. Harvey (1982) has suggested that sediment deposition downstream was determined by size and density of dredges, stream size, and proportion of fines in the substrate.

Sediment concentrations measured in BAS samplers indicated relative differences between sites in sediment load, but did not quantitatively measure deposition rates in samplers. As samplers were removed from the streambed, some fines were lost through the nets used to contain invertebrates within the sampler. Some BAS samplers below the dredge were completely silted over. Sediment fractions from these samplers would underestimate siltation rates.

Suction dredge mining alters streambed morphology by creating a pocket and pile streambed profile and forms bars as lag deposits, sorting out larger particles as finer particles are moved downstream. In Canyon Creek and BEF dredge tailings were generally displaced with the first high water and the streambed had returned to its predredging configuration after winter high flows. Two dredging operations on Canyon Creek removed or displaced large boulders to access placer deposits. This activity would alter substrate and streambed morphology for several years, or until a large flood event occurred. Dredges on Canyon Creek seemed to be spaced far enough apart, and operated at low enough levels during the study not to result in cumulative impacts. Harvey et al. (1982) found no cumulative dredge impacts in Butte Creek, CA. However, siltation from a large number of disturbed tributaries may overload downstream reaches with sediment, and impact aquatic productivity (Murphy et al. 1981).

The two 4 inch suction dredges that operated on the BEF produced extensive localized impacts. Dredge holes were excavated to a depth of 2 m. The organic material and sediment displaced downstream of dredging impacted abundances of benthic invertebrates in different ways depending upon ecological requirements. Most sediment had redeposited below the dredge in BEF. The study site in Canyon Creek below BEF showed minimal alterations in benthic invertebrate populations. Sediment and organic material in Canyon Creek samplers below BEF indicated elevated depositional rates as compared with the upper Canyon Creek site. The sedimentation did not result in major alterations in taxa composition.

Impacts by suction dredge mining to benthic invertebrate populations in Canyon Creek Basin were minimal at the present level of dredging when compared to bedload movement as the result of storms and snowmelt. Extensive literature exists which attests to the dispersal and reproductive powers of benthic invertebrates.

Dredging and Salmonids

In Canyon Creek, the diet of age-0 steelhead was predominately smaller invertebrates such as Baetis sp. and Chironomidae. Age-1 steelhead fed mainly on Baetidae and Chironomidae, although their overall diet included much larger invertebrates (Peltoperlidae, Perlodidae) than age-0 fish. Age-1 steelhead also fed on other salmonids. Age-2 steelhead fed on large aquatic insects such as Perlidae and Orohermes crepusculus, which were an important food item in terms of weight. Baetidae and Chironomidae were again the dominant food item numerically. Juvenile steelhead had a diurnal feeding trend for aerial insects in Canyon Creek. Although aquatic insects predominated over terrestrial insects in the diet of all steelhead age groups, terrestrial insects were a more important food source for juvenile steelhead than for age-0 fish. Johnson and Johnson (1981) found that aquatic invertebrates were the principal food of age-0 steelhead, although terrestrial prey were important diurnally. Nocturnal feeding by age-0 steelhead was almost exclusively upon aquatic invertebrate (Johnson and Johnson 1981). Jenkins et al. (1970) concluded that aerial insects were abundant food items diurnally, while benthic insects were abundant at night for hatchery rainbow trout introduced into a mountain stream.

The composition of steelhead diet for all age classes varied in different stream sections, most likely a result of changes in habitat and food availability. Hiss (1984) observed that steelhead exploited various temporarily abundant food resources in Willow Creek, CA. Jenkins et al. (1970) found that rainbow trout consumed aerial and benthic insects in roughly the same proportion as their occurrence in the drift. Johnson and Ringler (1980) concluded that the diet of steelhead was closely associated with the bottom fauna present.

Suction dredge mining at levels observed in Canyon Creek probably did not impact steelhead feeding. The mining did not significantly reduce the abundance of aquatic invertebrates (only species composition locally) and steelhead fed opportunistically. In fact, juvenile steelhead were observed feeding on invertebrates that had been entrained in and dislodged by dredge. Thomas (1985) observed cutthroat trout feeding on dislodged invertebrates in the dredge outfall.

The mean length and weight, and production of steelhead in Canyon Creek were similar to values reported in other northcoast streams. Length of steelhead in September in Canyon Creek was comparable, but somewhat shorter than length of steelhead from other northern California streams (Table 40). However, weight of juvenile steelhead from Canyon Creek was greater than weight from other areas and production (kg/ha) was as good or better than in other areas (Table 41). This would suggest that suction dredge mining did not impact growth or production of steelhead populations in Canyon Creek during the study. Impacts of dredging upon individual fish could be more variable, depending on the nature of the dredging operation and fish species involved. Harvey

(1982) found no differences in trout density attributable to dredging in general, however, in one pool reduced fish density was a direct response to dredging decreasing pool volume. He also observed that sculpin abundance downstream of the dredged area was significantly less than in the control area and suggested that the microhabitat of bottom oriented stream fishes such as sculpin are more readily altered by dredging than those of less benthic species.

Table 40. Length and weight for steelhead in September in northern California streams.

Author	Date	Location	Year	Age	Length (mm)	Weight (g)
Present study	1986	Canyon Creek	1982-1984	0	62	4.3
				1	116	18.0
				2	158	43.3
Pennington	1986	Manzanita Creek	1974	0	70-80	-
Barnhart et al.	1983	Browns Creek	1979-1982	0	≤98	3.2-6.2
				≥1	-	23.9-32.9
Reeves	1979	E. Fork of N. Fork Mad R.	1977	0	61	2.8
Cross	1975	Singley Creek	1969-1970	0	65	-
				1	105-125	-
Burns	1971	N. Fork Casper Creek	1967-1969	0	51-54	-
				1	106-123	-

Table 41. Production estimates for juvenile steelhead in September in northern California streams.

Author	Date	Location	Year	Production (kg/ha)
Present study	1986	Canyon Creek	1984	10.9 - 61.0
			1982	3.1 - 101.6
Pennington	1986	Manzanita Creek	1974	12.0 - 19.4
Barnhart et al.	1983	Browns Creek	1979-1982	21.3 - 77.7
Reeves	1979	E. Fork of N. Fork Mad River	1977	0.5 - 2.0
Cross	1975	Singley Creek	1969-1970	36.6 - 78.6
Burns	1971	Bummer Lake Creek	1967	39.8
Burns	1971	N. Fork Casper Creek	1967-1969	11.3 - 14.6

Entrainment of fish through suction dredges was not observed in this study. Griffith and Andrews (1981) observed high mortality (83% after 10 days, compared to 9% for controls) of suction dredge entrained rainbow sac fry. They observed no mortality for 20 underyearling brook trout (Salvelinus fontinalis) after entrainment. Harvey (1982) observed a small number of juvenile trout and sculpin that showed no immediate ill effects after dredge entrainment.

The level of suction dredge mining activity in Canyon Creek did not impact steelhead feeding, growth, and abundance. Present dredge mining regulations protect vulnerable life stages of salmonids (eggs and sac fry) from dredging activity in northern California streams. However, larger dredges, dredges operating in close proximity, or mined tailings introduced into the stream may produce greater impacts to salmonids. Dredge mining impacts to salmonids will vary with the natural sediment load and gradient of the stream, affecting the ability of the stream to displace sediment downstream and clean pools and riffles.

Since the completion of the Trinity River Division (TRD) of the Central Valley Project (CVP) in 1963, salmon and steelhead runs in the Trinity River Basin have severely declined - approximately 80% for chinook salmon (from an estimated 50,000+ spawners to 11,000), and 60% for steelhead (from an estimated 24,000 spawners to 11,000) (USFWS 1980). The few salmonid redds and carcasses located in Canyon Creek during the last 15 years reflect this trend of declining numbers of salmonids returning to spawn (Table 42). LaFaunce's 1965 estimate of 244 steelhead redds in Canyon Creek was most likely the result of spawner displacement due to the closure of Trinity River Dam in 1963 which forced steelhead to utilize the Trinity River and tributary streams below the dam. Subsequent surveys in Canyon Creek have found few or no redds and carcasses. The redd surveys during 1984-1985 were the most extensive ever conducted in Canyon Creek and probably are the most accurate record of salmonid escapement for the stream.

Table 42. Salmonid spawning surveys in Canyon Creek, Trinity County, California.

Year	Carcass count	Redd count					
		Steelhead			Chinook		Coho
	Chinook	Mainstem	Ripstein Gulch	Clear Gulch	Spring	Fall	
1964[a]		232		12			
1970[b]	16						
1972[c]		8					
1982[d]	31						
1983[d]	0						
1984[e]		15	4	0		8	
1985[f]	8	15		1	9	4	1

[a]LaFaunce, D.A. 1965. A steelhead spawning survey of the upper Trinity River system. Calif. Dept. Fish Game, Marine Resources Admin. Report No. 65-4. 5 pp.

[b]Rogers, D.W. 1970. A king salmon spawning escapement and spawning habitat survey in the upper Trinity River and its tributaries. Calif. Dept. Fish Game, Anadromous Fisheries Admin. Report No. 70-16. 13 pp.

[c]Rogers, D.W. 1972. A steelhead spawning survey of the tributaries of the upper Trinity River and the upper Hayfork drainage. Calif. Dept. Fish Game, Anadromous Fisheries Admin. Report No. 72-12. 6 pp.

[d]California Department of Fish and Game, Anadromous Fisheries Branch, files Arcata, California.

[e]Present study.

[f]Present study, carcass count by Calif. Dept. of Fish and Game, Anadromous Fisheries Branch, Arcata, California.

Water depth and velocity and gravel composition at steelhead spawning areas (redds) in Canyon Creek were similar to those reported by other authors (Table 43). Average steelhead redd size may have been less in Canyon Creek than reported elsewhere due to the small size of Trinity River adult steelhead (CH2M Hill 1985) and the selection of pocket gravels behind large boulders (Moffett and Smith 1950). The steelhead spawning season in the Trinity River system, reported by Moffett and Smith (1950), extends from February through the first week of June with a peak in late March and early April. LaFaunce (1965) observed a steelhead spawning peak in Trinity River tributaries between April 5 and 15 in 1964. In 1971, Rogers (1972) reported the peak occurred before April 1. In 1984 and 1985, steehead in Canyon Creek were observed spawning from early February through May with a 1984 season peak in early April and a 1985 season peak in late May. In 1985, high April streamflows may have delayed the spawning peak or obscured its earlier occurrence.

Table 43. Steelhead redd characteristics.

Location	Source	Redd area (m^2)	Water Depth (cm)	Water Velocity (cm/s)	Substrate particle size (mm)
Canyon Creek, CA	Present study	2.17	29.6	61.5	8.5 - 47.1
Dry Creek, CA	Carroll (1985)		17.3	34.1	6.3 - 76.1
Idaho	Orcutt, Pullman & Arp (1968)	5.17	-	-	1.27- 50.8
Oregon	Sams & Pearson (1963)	-	38.6	64.8	-
Prairie Creek, CA	Briggs (1953)	-	24.4	67.1	-
Oregon	Smith (1973)	-	41.7	62.8	-
Washington	Hunter (1973)	4.40	-	-	6.0 -102.0

During the fall of 1985, streamflow conditions permitted distinguishing between spring-run and fall-run chinook redds. Spring-run chinook constructed redds at a time when low streamflow in Canyon Creek did not permit fall-run chinook from the Trinity River to enter Canyon Creek. With upstream migration blocked, spring-run chinook spawning was separated geographically as well as in time from the spawning of fall-run chinook.

Water depth and velocity in Canyon Creek when spring-run chinook salmon were spawning were slightly less than parameters reported by other authors (Table 44), but streamflows were unusually low in early fall of 1985. The size of spring-run chinook salmon redds in Canyon Creek were similar to those reported by others with the exception of Moffett and Smith (1950). Their average redd size of 10.04 m^2 is quite large and may be the result of their attempts to establish the minimum area required by one spawning pair. Typically, spring-run chinook redds are from 3 to 6 m^2 (Marcotte 1985). The general pattern of spring-run chinook migrating and spawning higher in the watershed than fall-run chinook (Marcotte 1985; CH2M Hill 1985) was observed in Canyon Creek

Table 44. Spring-run chinook salmon redd characteristics.

Location	Source	Redd area (m^2)	Water Depth (cm)	Water Velocity (cm/s)
Canyon Creek, CA	Present study	4.32	19.8	40.9
Oregon	Smith (1973)	-	31.1	43.0
Oregon	Sams & Pearson (1963)	-	30.4	43.6
Columbia River Drainage, OR	Burner (1951)	3.26	22.2	61.0
Trinity River, CA	Moffett & Smith (1950)	10.04	-	-
Deer Creek, CA	Needham et al. (1943)	3.90	-	-

The water depth and velocity at fall-run chinook salmon spawning areas were similar to reported values (Table 45). The average size of fall-run chinook salmon redds in Canyon Creek was similar to the values reported by Burner (1951) and Buck (1986). Fall-run chinook salmon redds were all constructed in the lower 6 km of the study area and most were in the vicinity each year. Four redds were located within a few meters of a site selected during the previous chinook spawning season.

Table 45. Fall-run chinook salmon redd characteristics.

Location	Source	Redd area (m^2)	Water Depth (cm)	Water Velocity (cm/s)
Canyon Creek, CA	Present study	5.24	32.9	58.1
Trinity River, CA	Buck (1986)	5.30	43.0	44.0
Battle Creek, CA	Vogel (1982)	-	36.2	56.8
Oregon	Smith (1973)	-	39.0	49.7
Oregon	Sams & Pearsen (1963)	-	30.4	43.6
Coquille River, OR	Hamilton & Remington (1962)	-	36.6	71.6
Prairie Creek, CA	Briggs (1953)	-	33.5	61.0
Columbia River Drainage, OR	Burner (1951)	4.90	26.3	56.4

The time of peak chinook spawning in the upper Trinity River reported by Moffett and Smith (1950) coincided with observations in Canyon Creek. Spring-run chinook salmon spawning peaked in mid-October and fall-run chinook in late October/early November.

Spawning gravel did not appear to be a limiting factor in Canyon Creek. Salmonids spawned in only a portion of the gravel areas considered suitable and spawned in a few areas not judged as suitable. Fredle index values suggested the quality of spawning gravels in Canyon Creek was good to excellent for both chinook salmon and steelhead. At only two steelhead redds did the predicted survival-to-emergence drop below 70% to 50%. Low spawning escapement and high winter/spring flushing flows are more likely to be limiting factors upon in-stream fish production than available spawning habitat.

Moffett and Smith (1950) reported chinook fry emergence in the Trinity River Basin began in January and continued through May with spring-run fish emerging first. However, in Canyon Creek chinook fry were not observed until late February and small schools were not visible until April and May. Cold winter temperatures in Canyon Creek may slow down the developmental process and delay the majority of fry emergence until April and May. High streamflows during the late winter and spring may limit newly emerged fry to protective areas under rocks and ledges, which would have greatly reduced our ability to observe them. By June, chinook fry had left Canyon Creek and probably migrated downstream to the Trinity River with spring run-off. The downstream migration of juvenile chinook in the upper Trinity River usually peaks during May and June (Moffett and Smith 1950). Steelhead fry have been reported to emerge in the Trinity River from late April to June (Moffett and Smith 1950). In Canyon Creek, the observed timing of steelhead fry emergence from May through July was dependent upon the location of the redd. Steelhead fry emerged later in the season in the upper study area. Protracted spawning and colder waters in upstream areas probably prolonged steelhead hatching and incubation periods.

Canyon Creek currently supports a small population of spring-run chinook and summer-run steelhead. The few deep pools in the study area contain some of these adults, but the majority of summer-holding chinook and steelhead were found in the most common summer pool feature of Canyon Creek (1 to 1.5 m deep pools at stream meanders or bends). In August, spring-run chinook adults were generally concentrated in the middle section of the study area near Conrad and Rarick gulches. The well-developed overhead cover and frequent small pools of this area offered the most suitable summer-holding habitat for adults in Canyon Creek. During late October, these fish spawned in this same vicinity. Marcotte (1985) suggested that in the Trinity Basin only a small portion of the naturally spawning spring-run chinook was native and the remainder was of hatchery origin. In Canyon Creek, 17.2% of spring-run chinook were adipose fin clipped. Since 26.5% of the 1985 Lewiston hatchery spring-run adult returns were adipose clipped (G. Bedwell pers. comm.) it is highly probable that the majority of spring-run chinook in Canyon Creek were hatchery strays.

SUMMARY

At the present level of suction dredge mining in Canyon Creek, anadromous salmonids and habitat were only moderately affected. Spring-run chinook salmon and summer-run steelhead continued to hold in the creek and were in close proximity to dredging, some fish were located in pools within 50 m of active dredge operations. Salmonids spawned in the vicinity of the previous season's suction dredge mining, but salmonid redds were not located in dredge tailing piles. High stream flows transport materials that fill-in dredge holes and disperse tailing piles. The gravels dispersed by the high stream flows, which included dredge tailings, certainly composed a portion of the suitable spawning gravels each year.

Salmonid fry emergence and rearing in Canyon Creek did not appear to be impacted to a high degree by suction dredge mining. All chinook and coho salmon fry had emerged before the start of the dredging season. Some steelhead fry did emerge from areas in the upper creek during June and early July. It is possible, though unlikely, that some steelhead redds could be disturbed by dredging. However, limited dredge mining occurs in the upper creek and normal June stream flows are high enough to limit access by dredgers. Coho salmon and steelhead juveniles appeared to rear normally in the creek and were observed using dredge holes in the summer. Steelhead juveniles received the greatest exposure to dredging activity as they rear in Canyon Creek up to three years, but their feeding, growth and production did not seem to be impacted at the current level of dredge activity.

The effects of suction dredge mining on invertebrate colonization of BAS samplers were variables. Functional feeding groups had the following response in BEF: grazers and shredders were more abundant above dredging and gatherers more abundant below; no change in abundance was noted for filterers. Ecological differences between Canyon

Creek and BEF were also important in determining colonization of samplers. Overall, the impacts of suction dredge mining to benthic invertebrates at the study site were minimal.

Suction dredging in Canyon Creek results in a pocket and pile streambed profile. The impact of dredging on channel geomorphology were confined to the area dredged and immediately downstream. Most dredge sites were not noticeable the following year as high stream flows transported material and filled-in dredge holes and dispersed tailing piles. Water quality was good in Canyon Creek and only effected by suction dredging near the dredge when it was operated. Since dredges were operated only 2 to 4 hours a day and not every day, their effects on water quality were for a short time. The greatest amount of sediment produced in the drainage was not by suction dredging but by surface placer miners that sluiced tailings into the stream, road building and leaching of a flocculate from a settling pond. Stream temperatures were not changed by dredging.

The current CFG dredging codes were not always followed. We observed that some dredgers had undercut banks, channelized the stream and damaged riparian. Dredging the stream bank frequently resulted in channelizing the stream to maintain adequate water flow in the working area, bank undercutting and removing streamside vegetation. The damage to the streambank destablized the channel and accelerated bank erosion. Some dredgers removed large boulders with a dragline to access placer deposits and the removal could alter streambed morphology for several years.

The studies demonstrated that the impacts of suction dredge mining on fish and habitat were moderate. The impacts were seasonal and site specific. The current regulations controlling dredge aperature size and season appear adequate to protect habitat, but careful monitoring of mining activity is advised.

REFERENCES

Allen, R.K. 1968. New species and records of Ephemerella (Ephemerella) in western North America (Ephemeroptera: Ephemerellidae). J. Kansas Ent. Soc. 41:557-567.

Allen, R.K., and G.F. Edmunds, Jr. 1961. A revision of the genus Ephemerella (Ephemeroptera: Ephemerellidae) II. The subgenus Caudatella. Ann. Entomol. Soc. Amer. 54:603-612.

Allen, R.K., and G.F. Edmunds, Jr. 1962. A revision of the genus Ephemerella (Ephemeroptera: Ephemerellidae) V. The subgenus Drunella in North America. Misc. Publ. Entomol. Soc. Ameri. 3:147-179.

Allen, R.K., and G.F. Edmunds, Jr. 1963. A revision of the genus Ephemerella (Ephemerellidae) VI. The subgenus Seratella in North America. Ann. Entomol. Soc. Amer. 56:583-600.

Allen, R.K., and G.F. Edmunds, Jr. 1965. A revision of the genus Ephemerella (Ephemeroptera: Ephemerellidae) VIII. The subgenus Ephemerella in North America. Misc. Pulb. Entomol. Soc. Amer. 4:243-282.

Anderson, J.B., and W.T. Mason, Jr. 1968. A comparison of benthic macroinvertebrates collected by dredge and basket sampler. J. Water Pollut. Contr. Fed. 40:252-259.

Averill, C.V. 1941. Mineral Resources of Trinity County. Calif. J. Mines and Geology 37:8-89.

Barnhart, R.A., D. Bremm and R. Deibel. 1983. Fish habitat development project Browns Creek, Trinity County. Calif. Coop. Fish. Res. Unit, Humboldt State Univ., Arcata, CA. 141 pp.

Bjornn, T.C., M.A. Brusven, M.M. Molnau, F.J. Watts, R.L. Wallace, D.R. Neilson, M.F. Sandine, and L.C. Stuehrenberg. 1974. Sediment in streams and its effects on aquatic life. OWRT Research Technical Report, Project B-025-IDA. Water Resources Research Institute, Univ. of Idaho, Moscow, Idaho. 47 pp.

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. Klamt, E. Chaco, and C. Schaye. 1977. Transport of granitic sediment in streams and its effect on insects and fish. OWRT Research Technical Completion Report, Project B-036-IDA. Forest, Wildlife and Range Experiment Station, Univ. of Idaho, Moscow, Idaho. 43 pp.

Boussa, M.F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Mgmt. 18:227-239.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus sp. J. Fish. Res. Bd. Can. 9:265-323.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. Calif. Dept. Fish Game., Fish Bull. 94. 62 pp.

Britt, N.W. 1955. New methods of collecting bottom fauna from shoals or rubble bottoms of lakes and streams. Ecology 36(3):524-525.

Brown, H.P. 1972. Aquatic dryopoid beetles (Coleoptera) of the United States. Biota of freshwater ecosystems identification manual No. 6. Wat. Poll. Conf. Res. Ser., E.P.A. Washington, D.C. 82 pp.

Brusven, M.A., and K.W. Prather. 1971. Effects of siltation and coarser sediments on distribution and abundance of stream inhabiting insects. Technical Completion Report No. A-026-IDA. Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Brusven, M.A., and K.W. Prather. 1974. Influence of stream sediments on distribution of macrobenthos. J. Ent. Soc. of British Columbia 71:25-32.

Brusven, M.W., and S.T. Rose. 1981. Influence of substrate composition and suspended sediment on insect predation by the torrent sculpin, Cottus rotheus. Can. J. Fish. Aquat. Sci. 38:1444-1448.

Bryce, D., and A. Hobart. 1972. The biology and identification of the larvae of the Chironomidae (Diptera). Entomologist's Gazette 23:175-217.

Buck, M.K. 1986. Evaluation of constructed anadromous salmonid spawning riffles, Trinity River, California. Trinity River fish habitat studies - An assessment of anadromous fish habitat and related anadromous fish populations below Lewiston Dam in northwestern California, Task I. Calif. Coop. Fish. Res. Unit, Humboldt State Univ. 9 pp.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildl. Serv., Fish. Bull. 52(61):97-110.

Burns, J.W. 1971. The carrying capacity of juvenile salmonids in some northern California streams. Calif. Fish Game 57:44-57.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Am. Fish. Soc. 101:1-17.

California Department of Water Resources. 1964. Land and water use in Trinity River Hydrographic unit., Bull. No. 94-2. 115 pp.

California Department of Water Resources. 1980. Mainstem Trinity River Watershed Erosion Investigation. A report to the Trinity River Basin Fish and Wildlife Task Force. 35 pp.

California Department of Water Resources. 1983. Water conditions in California. Fall Report, October 1983. Calif. Coop. Snow Surveys, Bulletin 120-183.

Campbell, H.J. 1962. The effect of siltation from gold dredging on the survival of rainbow trout and eyed eggs in Powder River, Oregon. Oregon Game Commission Report. 3 pp.

Carroll, E.W. 1985. An evaluation of steelhead trout and instream structures in a California intermittent stream. M.S. Thesis, Humboldt State Univ., Arcata, CA. 62 pp.

Casey, O.E. 1959. The effects of placer mining (dredging) on a trout stream. Ann. Prog. Rept., Project F34-R-1, Pages 20-27 in Water Quality Investigations, Federal Aid in Fish Restoration, Idaho Dept. Fish and Game.

CH2M Hill. 1985. Klamath River basin fisheries resource plan. Prepared for U.S. Dept. Interior, Bureau of Indian Affairs, Redding, Calif.

Chutter, F.M. 1968. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiol. 34(1):57-76.

Clark, W.B. 1970. Gold districts of California. Calif. Div. of Mines and Geol., Bulletin 193. 186 pp.

Collins, P.L. 1977. Pages 4-15 in Humboldt State University computer program library documentation for program Growth. Humboldt State University Computer Center, Arcata, Calif.

Cooper, A.C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevin. Int. Pac. Salmon Fish. Comm., Bull. No. 18. 71 pp.

Cordone, A.J., and D.W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish Game 47:189-228.

Cordone, A.J., and S. Pennoyer. 1960. Notes on silt pollution in the Truckee River drainage. Calif. Dept. Fish Game, Inland Fish. Admin. Rept. No. 60-14. 25 pp.

Cox, D.P. 1967. Reconnaissance geology of the Helena quadrangle, Trinity County, Calif. Calif. Div. Mines Geol., Spec. Rept. No. 92:43-55.

Cross, P.D. 1975. Early life history of steelhead trout (Salmo gairdneri) in a small coastal stream. M.S. Thesis, Humboldt State Univ., Arcata, CA. 44 pp.

Crossman, J.S., and J. Cairns, Jr. 1974. A comparative study between two different artificial substrate samplers and regular sampling techniques. Hydrobiol. 44(4):517-522.

Crouse, M.R., C.A. Callahan, K.W. Malueg, and S.E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Trans. Am. Fish. Soc. 110:281-286.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24:631-641.

Cummins, K.W., and G.H. Lauff. 1969. The influence of substrate particle size on the micro-distribution of stream macrobenthos. Hydrobiol. 34(2):145-181.

Cummins, K.W., J.R. sedell, F.J. Swanson, G.W. Minshall, S.G. Fisher, C.E. Cushing, R.C. Peterson, and R.L. Vannote. 1981. Organic matter budgets for stream ecosystems: problems in their evaluation. Pages 299-353 in Barnes, J.R. and G.W. Minshall, eds. 1983. Stream ecology: application and testing of general ecological theory. Plenum Press, New York, NY. 399 pp.

Dickson, K.L., and J. Cairns, Jr. 1972. The relationship of fresh-water macroinvertebrate communities collected by floating artificial substrates to the MacArthur - Wilson Equilibrium Model. Am. Midl. Nat. 88(1):68-85.

Dickson, K.L., J. Cairns, Jr., and J.C. Arnold. 1971. An evaluation of the use of a basket-type artificial substrate for sampling macroinvertebrate organisms. Trans. Am. Fish. Soc. 100:553-559.

Dixon, W.J. 1981. Editor. BMDP statistical software. 1981 edition. Univ. of California Press, Berkeley, CA. 725 pp.

Duchrow, R.M., and W.A. Everhart. 1971. Turbidity Measurement. Trans. Am. Fish. Soc. 100:682-690.

Dunn, R.L. 1893. Canyon Creek District. Pages 482-483 in Calif. Mining Bureau Rept. No. 11.

Dunne, T. and L.B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company, S.F. and N.Y. 818 pp.

Edmunds, G.F., Jr., S.L. Jensen, and L. Berner. 1979. Mayflies of North and Central America. Univ. of Minn. Press, Minneapolis, Minn. 330 pp.

Egglishaw, H.J. 1964. The distributional relationship between the bottom fauna and plant detritus in streams. J. Animal Ecol. 33:463-476.

Elser, A.A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97:389-397.

Erickson, C.H. 1963. The relation of oxygen consumption to substrate particle size in two burrowing mayflies. J. Exp. Biol. 40:447-453.

Everhart, W.H., A.W. Eipper and W.D. Youngs. 1975. Principles of fishery science. Cornell University Press. Ithaca, NY. 288 pp.

Ferreira, R.F. 1976. Benthic invertebrate colonization of four artificial substrates in two small streams. Masters Thesis. Humboldt State Univ., Arcata, CA.

Freese, L. 1980. Canyon Creek summary report. Big Bar Ranger District, Shasta-Trinity National Forest. 17 pp.

Gammon, J.R. 1970. The effect of inorganic sediment on stream biota. EPA Water Quality Office, Water Pollution Control Research Series. 141 pp.

Gangmark, H.A. and R.G. Bakkala. 1960. A comparative study of unstable and stable (artificial channel) spawning streams for incubating king salmon at Mill Creek. Calif. Fish Game 46:151-164.

Gibbons, D.R., and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA Forest Service Gen. Tech. Rept. PNW-10.

Gore, J.A. 1982. Benthic invertebrate colonization: source distance effects on community composition. Hydrobiol. 94:183-193.

Griffith, J.S., and D.A. Andrews. 1981. Effects of a small suction dredge on fishes and aquatic invertebrates in Idaho streams. N. Am. J. Fish. Mgmt. 1:21-28.

Gudde, E.G. 1975. California Gold Camps. Univ. of California Press, Berkeley, CA. 467 pp.

Guy, H.P. 1970. Laboratory theory and methods for sediment analysis. Techniques of water resources investigations of the USGS, Book 5, Chapter C-1. U.S. Government Printing Office, Washington, D.C., USA.

Hamilton, J.A.R. and J.R. Remington. 1962. Salmon and trout of the South Fork Coquille River in relation to the Eden Ridge hydroelectric project. Pacific Power and Light Co., Portland, Oregon. 83 pp.

Harrington, J.M. 1983. An evaluation of techniques for collection and analysis of benthic invertebrate communities in second order streams in Redwood National Park. M.S. Thesis, Humboldt State Univ., Arcata, CA. 46 pp.

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22(4):1035-1081.

Harvey, B.C. 1982. Effects of suction dredge mining on fish and invertebrates in California foothill streams. Masters Thesis, Univ. of California, Davis, CA.

Harvey, B.C., K. McCleneghan, J.D. Linn, and C.L. Langley. 1982. Some physical and biological effects of suction dredge mining. Calif. Dept. Fish Game, Lab Report No. 82-3. 20 pp.

Hausle, D.A., and D.W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout. Trans. Am. Fish. Soc. 105:57-63.

Hawkins, C.P., and J.R. Sedall. 1981. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams. Ecology 62(2):387-397.

Hiss, J.M. 1984. Diet of age-0 steelhead trout and speckled dace in Willow Creek, Humboldt County, California. M.S. Thesis, Humboldt State Univ., Arcata, CA. 51 pp.

Hunter, J.W. 1973. A discussion of game fish in the state of Washington as related to water requirements. Rept. by Fish Mgt. Div. of Wash. St. Dept. of Game to Wash. St. Dept. of Ecology. 66 pp.

Hynes, H.B.N. 1974. The biology of polluted waters. Univ. of Toronto Press, Toronto, Canada. 202 pp.

Irwin, W.P. 1960. Geologic reconnaissance of the northern coast ranges and Klamath Mountains, California, with a summary of the mineral resources. Calif. Div. of Mines, Bulletin 179. 80 pp.

Iwamoto, R.N., E.O. Salo, M.A. Madej, and R.L. McComas. 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria. EPA 910/9-78-048.

Jenkins, T.M., Jr., C.R. Feldmeth, and G.V. Elliot. 1970. Feeding of rainbow trout (Salmo gairdneri) in relation to abundance of drifting invertebrates in a mountain stream. J. Fish. Res. Bd. Canada 27:2356-2361.

Johnson, J.H., and E.Z. Johnson. 1981. Feeding periodicity and diel variation in diet composition of subyearling coho salmon, Oncorhynchus kisutch, and steelhead, Salmo gairdneri, in a small stream during summer. Fish. Bull. 79(2):370-376.

Johnson, J.H., and N.M. Ringler. 1980. Diets of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri) relative to prey availability. Can. J. Zool. 58:553-558.

Jones, A.G. 1981. Trinity County Historical Sites. Trinity County Historical Society, Weaverville, CA. 422 pp.

Kaston, B.J. 1978. How to know the spiders. Wm. C. Brown Company, Publishers, Dubuque, Iowa. 272 pp.

LaFaunce, D.A. 1965. A steelhead spawning survey of the upper Trinity River system. Calif. Dept. Fish Game, Marine Resources Admin. Rept. No. 65-4. 5 pp.

LaPerriere, J.D. 1984. Effects of placer mining on primary production of Alaskan streams. U.S. Fish and Wildlife Service, Research Information Bulletin No. 84-76.

Lewis, R. 1962. Results of gold dredge investigation. Calif. Dept. Fish Game, Memorandum, Sept. 17, 1962. 7 pp.

Lotspeich, F.B., and F.H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. Research Note PNW-369. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. USA. 11 pp.

Luedtke, R.J., and M.A. Brusven. 1976. Effects of sand sedimentation on colonization of stream insects. J. Fish. Res. Bd. Can. 33(9):1881-1886.

Marcotte, B.D. 1985. Life history, status, and habitat requirements of spring-run chinook salmon in California. Lassen National Forest, Chester, CA. 36 pp.

McAfee, W.R. 1966. Rainbow trout. Pages 192-215. In A. Calhoun (ed.), Inland Fisheries Management. Calif. Dept. Fish Game, Sacramento, CA.

McClelland, W.T., and M.A. Brusven. 1980. Effects of sedimentation on the behavior and distribution of riffle insects in a laboratory stream. Aquatic Insects 2(3):161-169.

McCleneghan, K., and R.E. Johnson. 1983. Suction dredge gold mining in the Mother Lode region of California. Calif. Dept. Fish Game, Environ. Serv. Branch Admin. Rept. 83-1. 16 pp.

McNeil, W.J., and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish Wildl. Serv. Spec. Sci. Report - Fisheries No. 469. 15 pp.

Meeham, W.R. 1971. Effects of gravel cleaning on bottom organisms in three southeast Alaska streams. Prog. Fish. Cult. 33(2):107-111.

Meeham, W.R., and D.N. Swanson. 1977. Effects of gravel morphology on the fine sediment accumulation and survival of incubating salmon eggs. Research Paper PNW-220. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, USA. 16 pp.

Merritt, R.W., and K.W. Cummins. 1984. An introduction to the aquatic insects of North America, second edition. Kendall/Hunt Publishing Co., Dubuque, Iowa. 722 pp.

Minshall, G.W. 1981. Structure and temporal variations of the benthic macroinvertebrate community inhabiting Mink Creek, Idaho, U.S.A., a 3rd order Rocky Mountain stream. J. Freshwater Ecol. 1:13-26.

Minshall, G.W., and J.N. Minshall. 1977. Microdistribution of benthic invertebrates in a Rocky Mountain (U.S.A.) stream. Hydrobiol. 55(3):231-249.

Moffett, J. and S. Smith. 1950. Biological investigations of the fishery resources of Trinity River, California. U.S. Fish. Wildl. Serv., Spec. Sci. Rept. - Fish. No. 12. 71 pp.

Moring, J.R. and R.L. Lantz. 1975. The Alsea Watershed Study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part 1 - Biological studies. Oregon Wildl. Comm. Fish. Res. Rept. 9. 66 pp.

Moyle, P.B. 1976. Some effects of channelization on the fisheries and invertebrates of Rush Creek, Modoc County, California. Calif. Fish Game 62:179-186.

Murphy, M.L., and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38:137-145.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Am. Fish. Soc. 110:469-478.

Needham, P.R., H.A. Hanson, and L.P. Parker. 1943. Supplementary report on investigations of fish-salvage problems in relation to Shasta Dam. U.S. Fish Wildl. Serv., Spec. Sci. Rept. No. 26. 49 pp.

Newbold, J.D., D.C.Erman, and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37:1076-1085.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. SPSS: statistical package for the social sciences. McGraw-Hill Book Co., New York, NY. 675 pp.

Nuttall, P.M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Freshwater Biol. 2:181-186.

Orcutt, D.R., B.R. Pullman, and A. Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. Trans. Am. Fish. Soc. 97:42-45.

Pearson, W.D., and D.R. Franklin. 1968. Some factors affecting drift rates of Baetis and Simuliidae in a large river. Ecology 49:75-81.

Pennington, H.M. 1986. Emigration and mortality of juvenile steelhead in a nursery stream. M.S. Thesis, Humboldt State University, Arcata, California. 55 pp.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA Intermountain Forest and Range Experiment Station, General Technical Report INT-138.

Prokopovich, N.P., and K.A. Nitzberg. 1982. Placer mining and salmon spawning in American River Basin, California. Bull. of the Assoc. of Engineering Geologists.

Rees, W.H. 1959. Effects of stream dredging on young silver salmon (Oncorhynchus kisutch) and bottom fauna. WA. Dept. Fish., Fish Res. Paper 2(2):53-65.

Reeves, G.H. 1979. Population dynamics of juvenile steelhead trout in relation to density and habitat characteristics. M.S. Thesis, Humboldt State Univ., Arcata, CA. 67 pp.

Reeves, G.H. and T.D. Roelofs. 1982. Influence of forest and rangeland management on anadromous fish habitat in western North America - Rehabilitating and enhancing stream habitat: 2. field applications. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Gen. Tech. Rept. PNW-140. 38 pp.

Reiser, D.W. and T.C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in western North America - Habitat requirements of anadromous salmonids. USDA Forest Service, Pacific Northwest Forest and Range Experiment Service, Pacific Northwest Forest and Range Experiment Station, Gen. Tech. Rept. PNW-96. 54 pp.

Reynolds, J.B. 1984. Effects of placer mining sediments on arctic grayling. U.S. Fish Wildl. Serv., Research Information Bulletin No. 84-77.

Rogers, D.W. 1972. A steelhead spawning survey of the tributaries of the upper Trinity River and the upper Hayfork drainage. Calif. Dept. Fish Game, Anadromous Fish. Admin. Rept. No. 72-12. 6 pp.

Rosenburg, D.M., and V.H. Resh. 1982. The use of artificial substrates in the study of freshwater benthic macroinvertebrates. Pages 175-235 in J. Cairns, Jr. (ed.). Artificial Substrates. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. 279 pp.

Sams, R.E. and L.S. Pearson. 1963. A study to develop methods for determining spawning flows for anadromous salmonids. Oregon Fish Comm., Portland, OR. 56 pp.

Saunders, J.W., and M.W. Smith. 1965. Changes in a stream population of trout associated with increased silt. J. Fish. Res. Bd. Can. 22(2):395-404.

Shaw, P.A., and J.A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. Calif. Fish Game 29:29-41.

Shelton, J.M., and R.D. Pollock. 1966. Siltation and egg survival in incubation channels. Trans. Am. Fish. Soc. 95:183-187.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Trans. Am. Fish. Soc. 113:142-150.

Slack, K.V., R.C. Averett, P.E. Greeson, and R.G. Lipscomb. 1973. Methods for collection and analysis of aquatic biological and microbiological samples. Techniques of Water-Resources Investigations of the U.S. Geological Survey. Chapter A4, book 5, laboratory analysis. 165 pp.

Smith, A.K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Am. Fish. Soc. 102:312-316.

Smith, O.R. 1939. Placer mining silt and it's relation to salmon and trout on the Pacific coast. Trans. Am. Fish. Soc. 69:225-230.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry. 2nd edition. W.H. Freeman and Company, San Francisco, CA. 859 pp.

Sumner, F.H., and O.R. Smith. 1940. Hydraulic mining and debris dams in relation to fish life in the American and Yuba rivers of California. Calif. Fish Game 26:2-22.

Tebo, L.B., Jr. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. Prog. Fish. Cult. 17(2):64-70.

Thomas, V.G. 1985. Experimentally determined impacts of a small, suction gold dredge on a Montana stream. N. Am. J. Fish. Mgmt. 5:480-488.

Turnpenney, A.W.H., and R. Williams. 1980. Effects of sedimentation on the gravels of an industrial river system. J. Fish Biol. 17:681-693.

U.S. Fish and Wildlife Service. 1980. Trinity River instream flow study, Lewiston Dam to the North Fork. A report to the Trinity River Basin Fish and Wildlife Task Force. 48 pp.

Usinger, R.L. 1956. Aquatic insects of California. Univ. of California Press, Berkeley, CA. 508 pp.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.

Vogel, D.A. 1982. Preferred spawning velocities, depths, and substrates for fall chinook salmon in Battle Creek, California. Unpub. Rept., U.S. Fish Wildl. Serv., Fish. Assist. Office, Red Bluff, CA. 8 pp.

Waters, T.F. 1964. Recolonization of denuded stream bottom areas by drift. Trans. Am. Fish. Soc. 93:311-315.

Weber, C.I. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA 670/4-73-001.

Welton, J.S., and M. Ladle. 1979. Two sediment trap designs for use in small rivers and streams. Limnol. Oceanogr. 24(3):588-592.

Wickham, G.M. 1967. Physical microhabitat of trout. M.S. Thesis, Colo. State Univ., Fort Collins. 42 pp.

Wiggins, G.B. 1977. Larvae of the North American caddisfly genera. Univ. of Toronto Press, Toronto, Canada. 401 pp.

Wilhm, J.L. 1970. Range of diversity index in benthic macroinvertebrate populations: Wat. Poll. Control Fed. J. 42(5)R221-R224.

Wilhm, J.L., and T.C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18:477-481.

Williams, D.D. 1980. Some relationships between stream benthos and substrate heterogeneity. Limnol. Oceanogr. 25(1):166-172.

Williams, D.D., and J.H. Mundie. 1978. Substrate size selection by stream invertebrates and the influence of sand. Limnol. Oceanogr. 23(5):1030-1033.